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EXTREMELY LOW FREQUENCY (ELF) FIELD STRENGTH MEASUREMENTS MADE --ETC(U)
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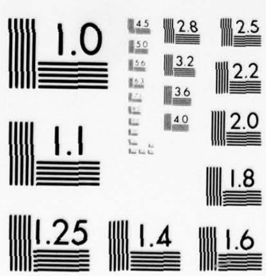

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NUSC Technical Report 5853

Extremely Low Frequency (ELF) Field Strength Measurements Made in Connecticut During 1976

Peter R. Bannister
Submarine Electromagnetic
Systems Department

11 September 1978

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PREFACE

This report was prepared under NUSC Project No. A-590-07, "Project SEAFARER ELF Propagation Studies" (U), Principal Investigator, P. R. Bannister (Code 341); Navy Program Element No. 11401 and Project No. X0792, Naval Electronic Systems Command, Special Communications Project Office, CAPT C. D. Pollak (Code PME-117) Program Manager, ELF Communications Division, Dr. B. Kruger (Code PME-117-21), Director.

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REVIEWED AND APPROVED: 11 September 1978

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Horizontal magnetic field strength measurements (both amplitude and relative phase) at 76 ± 4 Hz were made in Connecticut from August to December 1976 to further investigate sunrise, daytime, sunset, nighttime, and seasonal extremely low frequency (ELF) propagation variations. The transmission source for these 1.6 Mm range measurements was the U.S. Navy ELF Wisconsin Test Facility (WTF). The principal observations obtained from these measurements were (1) that ELF nighttime propagation is much more variable than daytime propagation, (2) that the nighttime field strength amplitude usually

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20. Abstract (Cont'd)

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minimized around 0600 to 0800 GMT, whereas the nighttime relative phase maximized about an hour earlier, (3) that increases in geomagnetic activity were usually accompanied by decreases in the minimum nighttime field strength, (4) that the repetition rate between the lowest measured minimum nighttime field strengths was nearly equal to the solar rotation period, (5) that the "Halloween effect" was observed for the seventh year in a row, (6) that the average relative phase difference between daytime and nighttime propagation conditions was 22 degrees, which corresponds to a relative phase velocity difference $\Delta(c/v)$ of 0.15, (7) that phase velocity changes occurring during nighttime propagation conditions occasionally are greater than changes associated with the sunrise-sunset terminators crossing the transmitter or receiver locations, and (8) that large decreases in field strength amplitude were not accompanied by large decreases in effective atmospheric noise levels.

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INTRODUCTION

During the last 7 years, the Naval Underwater Systems Center (NUSC) has sporadically made farfield, extremely low frequency (ELF), horizontal magnetic field measurements in Connecticut.[1-7] Prior to October 1971, the local measurement site was located in the Nehantic State Forest, East Lyme, Connecticut. From October 1971 to November 1975, it was located in Hammonassett State Park, Madison, Connecticut. At both of these measurement sites, NUSC narrowband ELF field intensity receivers were used.[8]

Since August 1976, a SEAFARER* ELF receiver (AN/BSR-1) located at NUSC, New London, Connecticut, has been used. The receiver is connected, via a microwave link, to a loop receiving antenna located at Fishers Island, New York (about 6.2 miles (10 km) from New London). The receiving antenna is located approximately 170 ft (50 m) from a NUSC building, at Fishers Island, which houses the ELF preamplifier and associated circuitry.

The transmission source for the 1.6 Mm range measurements was the U.S. Navy Wisconsin Test Facility (WTF), located in the Chequamegon National Forest in northcentral Wisconsin about 8 km south of the village of Clam Lake. The facility consists of two 22.5 km antennas. One antenna is located in approximately the NS direction, and the other antenna is located in approximately the EW direction. Each antenna is grounded at both ends. At 76 Hz, the electrical axis of the NS antenna is 14°E of N, whereas the electrical axis of the EW antenna is 114°E of N.[9-11] The WTF antenna array can be steered to any direction, and its radiated power is approximately 1 watt.

This report discusses the results and observations of the 1976 Connecticut measurements and compares them with other data taken previously.

1976 CONNECTICUT MEASUREMENTS

Daily field strength and effective noise measurements have been taken in Connecticut (via the Fishers Island microwave link) since August 1976. The main purpose of these measurements is to further investigate sunrise, daytime, sunset, nighttime, and seasonal ELF propagation variations. A secondary purpose is to establish a mid-latitude effective noise data base. The results of the field strength measurements are discussed in this report; the 76 Hz effective noise measurement results are discussed in a separate

*SEAFARER (formerly called SANGUINE) is an arbitrary designation applied to ongoing ELF research by the U.S. Navy. The term designates work directed toward the implementation of an ELF shore-to-ship radio communication system.

report.[12]

The daily field strength values (both amplitude and relative phase) measured in Connecticut from August to December 1976 are plotted against GMT in the appendix to this report. The WTF antenna phasing angle ψ was 21 degrees during most of this time period. For each of these plots, the effective integration time per sample was 1,792 seconds (approximately 30 minutes) and the average signal-to-noise ratio (SNR) was 22 to 27 dB. (Each 1,792-second effective integration time sample is an average of two 896-second or of one 1,792-second actual integration time sample.)

Altogether, field strength measurements were taken 14 to 24 hours each day for approximately 120 days. This is approximately the same number of 76-Hz band measurement days that occurred in Connecticut from 1970 through 1975. Thus, we have essentially doubled our measurement base. Also for the first time, detailed measurements (both amplitude and relative phase) were made during both the sunrise (SRTP) and sunset (SSTP) transition periods.

The August through December daily field strength averages are presented in tables 1 through 5, while a comparison of the 1976 monthly averages is given in table 6. From table 6, it can be seen that the average nighttime field strength decreased by approximately 1 dB from August to December, whereas the average daytime field strength decreased by only 0.5 dB. Also, the 1976 daytime and nighttime yearly average values (-144.1 and -146.0 dBA/m) were almost identical to the 1970-74 yearly average values (-144.0 and -145.8 dBA/m).[5] The yearly average relative phase difference between daytime and nighttime propagation conditions was 22 degrees, which corresponds to a relative phase velocity difference $\Delta(c/v)$ of 0.15. This value (0.15) is in excellent agreement with previous measurements.[7,13,14]

Referring to the daily field strength plots in the appendix, we see that during this measurment period, the field strength variations were not as severe as measured in Connecticut from 1970 to 1975.[1-7] However, as previously observed, ELF nighttime propagation was much more variable than ELF daytime propagation.

The fact that field strength fluctuations were less severe is not surprising since during August - December 1976, we were in a low part of the sunspot cycle. That is, since there is a close correlation between geomagnetic disturbances and solar activity as manifested by sunspots, and because geomagnetic activity appears to be correlated with ELF field strength variations,[5,15,16] we would not expect many severe ELF field strength variations during the low portion of the sunspot cycle.

A typical "quiet ionospheric conditions" field strength plot is presented in figure 1. Both the 7 and 8 November daytime and nighttime field strengths exhibited little sample-to-sample variation in either amplitude or relative phase. The nighttime field strengths were 2 to 2.5 dB lower than the daytime field strengths, with a gradual increase in amplitude (and a gradual decrease in relative phase) during the SRTP and a gradual decrease in amplitude (and a gradual increase in relative phase) during the SSTP.

Table 1. August 1976 Connecticut Daily Field Strength Averages

Date	WTF Phasing (Degrees)	Nighttime H_ϕ (dBA/m)	SRTP H_ϕ (dBA/m)	Daytime H_ϕ (dBA/m)	SSTP H_ϕ (dBA/m)	$\Delta\phi$ (Degrees) (Night-Day)
8/3/76	207	--	--	-144.1	--	--
8/4	207	-145.9	-145.8	-144.1	-145.0	--
8/5	207	-145.6	-145.6	-144.5	-145.6	25
8/6	207	-146.4	-145.5	--	-145.7	--
8/13	EW	--	--	-143.9	--	24
8/14	EW	-145.8	-145.4	-144.0	-144.5	26
8/15	110	-146.4	--	--	-145.5	--
8/17	117	-147.3	-146.0	--	-147.7	--
8/18	207	-145.7	-145.8	-144.3	-145.3	32
8/19	111	--	--	-144.8	--	26
8/20	111	-145.8	--	-145.3	-144.2	--
8/22	21	-145.3	-144.8	-143.8	-144.5	23
8/23	21	-144.9	-144.7	-144.1	-144.0	21
8/24	21	-145.4	--	-143.7	-144.9	26
8/24	111	--	--	-147.0	--	23
8/25	111	-147.9	-146.9	-145.9	-146.7	22
8/26	201	--	--	-144.7	--	--
August Average (Normalized to = 21°)		-145.5	-145.1	-143.9	-144.7	24.8

Table 2. September 1976 Connecticut Daily Field Strength Averages (ψ = 21°)

Date	Nighttime H_ϕ (dBA/m)	SRTP H_ϕ (dBA/m)	Daytime H_ϕ (dBA/m)	SSTP H_ϕ (dBA/m)	$\Delta\phi$ (Degrees) (Night-Day)
9/7/76	---	---	-143.3	---	--
9/8	-145.1	-144.9	-143.4	-145.1	--
9/9	---	---	-143.8	---	--
9/10	-145.1	-144.3	-143.5	-144.0	20
9/11	-145.9	-144.9	-144.1	-144.4	25
9/12	-145.7	-145.9	-143.9	-144.4	22
9/13	-145.6	-144.9	-143.7	-145.3	27
9/14	---	---	-144.3	-144.5	--
9/15	-145.8	-145.2	-143.9	-144.2	25
9/16	-145.8	-145.4	-143.9	-144.2	26
9/17	-145.3	-145.2	-143.6	-144.2	24
9/18	-146.2	-145.4	-144.1	-144.4	21
9/19	-145.9	-145.3	-144.1	-145.0	18
9/20	-145.9	-145.0	-143.8, -145.9*	-145.3	5
9/21	-146.4*	-147.3*	-146.1*	-146.7*	21
9/22	-145.9	-145.1	-144.2	-145.6	16
9/23	-145.7	-145.3	-143.8	-145.5	21
9/24	-145.9	-145.6	-143.9	-145.3	17
9/25	-145.9	-145.0	-143.7	-144.8	25
9/26	-145.6	-144.5	-143.4	-144.9	21
9/27	---	---	-143.8	-143.8	--
9/28	-145.5	-143.8	-143.8	-144.7	22
9/29	-145.4	-144.6	-143.7	-145.1	33
9/30	-145.9	-144.8	-143.7	-144.5	23
September Average	-145.7	-145.0	-143.8	-144.7	21.7

*ψ = 110°

Table 3. October 1976 Connecticut Daily Field Strength Averages ($\psi = 21^{\circ}$)

Date	Nighttime H_{ϕ} (dBA/m)	SRTP H_{ϕ} (dBA/m)	Daytime H_{ϕ} (dBA/m)	SSTP H_{ϕ} (dBA/m)	$\Delta\phi$ (Degrees) (Night-Day)
10/1/76	-146.2	-144.5	-143.5	-144.2	20
10/2	-146.2	-144.7	-143.6	-144.4	40
10/3	-145.9	-145.2	-143.8	-144.9	43
10/4	---	---	-143.4	-144.7	--
10/5	-145.8	-144.2	-143.4	-144.0	22
10/6	-145.5	-144.5	-143.5	---	24
10/7	---	---	-143.5	-144.3	--
10/8	-145.5	-144.7	-143.4	-143.6	--
10/9	-145.2	-144.6	-143.5	-144.3	21
10/10*	-145.9	-145.5	-144.7	-145.0	27
10/11*	-146.2	-145.7	-145.2	-145.1	23
10/12*	-146.5	-145.7	-145.0	---	23
10/13*	---	---	---	-145.9	--
10/14*	-146.9	-146.6	-145.9	---	22
10/15*	---	---	-146.1	-146.7	--
10/16*	-147.2	-146.8	-145.9	-146.0	--
10/17*	-147.3	-147.2	-146.6	-146.4	--
10/18*	-147.4	-147.0	---	---	--
10/20*	-146.5	-146.9	---	---	--
10/21	-146.3	---	-144.5	---	--
10/22	---	---	---	-145.3	--
10/23	-146.4	-145.9	-144.4	---	24
10/24	-146.3	-146.2	-144.4	---	19
10/25	-146.5	-145.5	-144.5	---	21
10/26	-146.0	-145.0	-144.0	-145.3	21
10/27	-145.9	-145.3	-144.1	-145.1	17
10/28	-145.8	-145.0	-144.2	-144.6	16
10/29	-145.9	-145.4	-144.4	-144.9	21
10/30	-147.8	-147.0	-145.6	-146.2	23
10/31	-148.1	-147.1	-144.5	-146.1	23
October Average	-146.0 -146.7*	-145.1 -146.4*	-143.9 -145.6*	-144.7 -145.8*	23.7

*$\psi = 110^{\circ}$

Table 4. November 1976 Connecticut Daily Field Strength Averages ($\psi = 21^{\circ}$)

Date	Nighttime H_{ϕ} (dBA/m)	SRTP H_{ϕ} (dBA/m)	Daytime H_{ϕ} (dBA/m)	SSTP H_{ϕ} (dBA/m)	$\Delta\phi$ (Degrees) (Night-Day)
11/1/76	-146.4	-145.7	-144.0	-145.1	21
11/2	-146.6	-145.5	---	-145.0	--
11/3	-146.4	-145.7	-144.2	-145.2	24
11/4	-146.5	-145.4	-144.4	---	18
11/5	-146.4	-145.0	-143.9	---	21
11/6	-146.0	-145.8	-144.4	---	23
11/7	-146.4	-145.2	-144.1	-145.1	22
11/8	-146.8	-145.8	-144.4	---	16
11/9	-146.8	-145.5	-144.6	---	23
11/10	-146.1	-145.6	-144.5	---	23
11/11	-146.4	-145.4	-144.8	---	17
11/12	-146.7	-146.0	-144.8	---	26
11/16	-146.3	-145.4	---	---	--
11/17	-146.4	-146.0	---	---	--
11/18	-146.2	-146.0	---	---	--
11/19	-146.7	-146.0	---	---	--
11/20	-146.0	-145.4	-144.1	---	20
11/21	-145.8	-145.3	-144.3	---	23
11/22	-146.5	-145.9	-145.0	---	26
11/23	-146.1	-145.6	-144.7	---	23
11/24	-146.0	-145.9	-144.6	---	18
11/25	-146.8	-146.1	-144.4	---	19
11/26	-145.8	-145.0	-144.2	---	16
11/27	-146.2	-145.9	-144.4	---	16
11/28	-145.9	-145.8	-144.4	---	19
11/29	-145.7	-145.9	-144.5	---	14
November Average	-146.3	-145.6	-144.4	-145.1	20.3

Table 5. December 1976 Connecticut Daily Field Strength Averages (ψ = 21°)

Date	Nighttime H_ϕ (dBA/m)	SRTP H_ϕ (dBA/m)	Daytime H_ϕ (dBA/m)	$\Delta\phi$ (Degrees) (Night-Day)
12/1/76	-146.2	-145.0	-143.9	15
12/2	-146.1	-145.2	-144.5	16
12/3	-146.4	-145.3	-144.2	23
12/4	-146.3	---	---	--
12/5	-145.8	-145.3	-143.8	22
12/6	-145.4	---	-144.2	--
12/7	-146.2	-145.4	-144.6	24
12/8	-146.9	-145.5	-145.0	25
12/9	-147.0	-146.2	-144.8	21
12/10	-145.9	-145.7	-144.3	20
12/11	-146.3	-145.7	-144.4	25
12/12	-146.4	-145.6	-144.4	20
12/13	-145.9	-145.6	---	--
12/14	-146.3	-146.1	---	--
12/15	-146.5	-145.7	---	--
12/16	-146.5	-146.1	---	--
12/17	-146.2	-145.7	---	--
12/18	-147.3	-145.5	-144.2	21
12/19	-146.5	-145.7	-144.3	26
12/20	-146.0	-145.7	---	--
12/22	-146.3	-145.6	-144.0	17
12/23	-146.5	-146.3	-145.1	21
12/24	-146.4	-146.0	-144.4	19
12/28	-146.8	-146.0	-144.6	23
12/29	-147.2	-145.9	-145.1	12
12/30	-146.5	-146.5	-144.6	17
12/31	-146.7	-146.0	-144.6	18
December Average	-146.4	-145.7	-144.4	20.3

Table 6. Comparison of 1976 Monthly Averages (ψ = 21°)

Month	Nighttime H_ϕ (dBA/m)	SRTP H_ϕ (dBA/m)	Daytime H_ϕ (dBA/m)	SSTP H_ϕ (dBA/m)	$\Delta\phi$ (Degrees)	Δ(c/v)
August	-145.5	-145.1	-143.9	-144.7	24.8	0.17
September	-145.7	-145.0	-143.8	-144.7	21.7	0.15
October	-146.0	-145.1	-143.9	-144.7	23.7	0.16
November	-146.3	-145.6	-144.4	-145.1	20.3	0.14
December	-146.4	-145.7	-144.4	---	20.3	0.14
Average	-146.0	-145.3	-144.1	-144.8	22.2	0.15

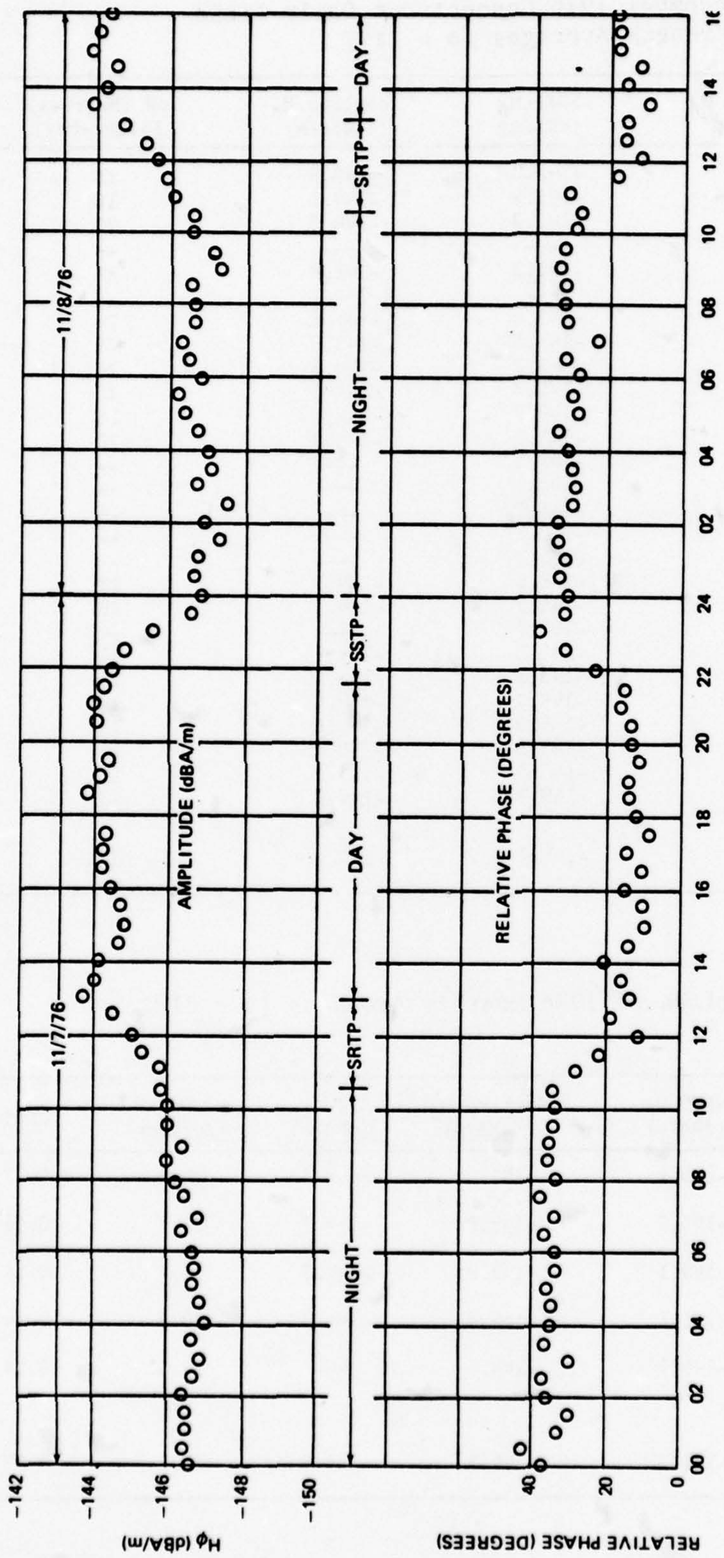

Figure 1. 7 and 8 November Connecticut Field Strengths Versus GMT (ψ = 21°)

Referring to the appendix, we see that during many measurement days, the nighttime field strength amplitude reached a minimum around 0600 to 0800 GMT. Conversely, the nighttime relative phase reached a maximum about an hour earlier. This phenomenon is further illustrated in table 7 and figures 2 through 4. A comparison of 34 nighttime minimum amplitude times with the corresponding maximum relative phase times (table 7) yields an average minimum nighttime field strength amplitude time of approximately 0700 GMT, and an average maximum nighttime relative phase time of approximately 0600 GMT.

On 18 September (figure 2), the field strength amplitude steadily decreased 5 dB from 2300 to 0630, and then steadily increased 5 dB from 0630 to 1200. Meanwhile, the relative phase increased 20 degrees from 0230 to 0500, and then decreased 15 degrees from 0500 to 0800.

The data taken on 21 September (figure 3) are quite irregular in that the 0000 to 0900 field strengths are almost mirror images of the 0900 to 1800 field strength amplitudes. The amplitude decreased 5 dB from 0500 to 0900, and then increased 5 dB from 0900 to 1300. On the other hand, the relative phase increased 18 degrees from 0500 to 0730 and decreased 19 degrees from 0730 to 0900.

On 23 September (figure 4), the nighttime field strength amplitude decreased approximately 4.5 dB from 0500 to 0700, and then increased approximately 4 dB from 0700 to 1100. Meanwhile, the relative phase increased 15 degrees from 0430 to 0630, and then decreased 22 degrees from 0630 to 0800.

Recent theoretical and experimental results strongly indicate that these nighttime midlatitude field strength reductions are a result of charged particles dumped from the outer radiation belt following their insertion into the trapping zone during the early stages of magnetic storms.[15-18] Spjeldvik and Thorne have shown that during storm recovery periods, electron precipitation dominates other D-region ionization mechanisms in the middle latitudes, thus lowering the effective ionospheric reflecting height over certain portions of the propagation path.[17,18] The time of the lowest nighttime field strengths (0600 to 0800 GMT) coincides with the farthest southern displacement of the auroral oval, and presumably indicates the time at which precipitated energetic electrons would reach their southernmost extent into the middle latitudes.[16]

Figures 5 through 9 illustrate some examples of extremely abnormal relative phase variations. On 25 September (figure 5), the field strength amplitude steadily increased from the early morning minimum (0700), through the SRTP, and leveled off at the average daytime value with very little sample-to-sample variation. The relative phase remained essentially constant from midnight to 0500 and also during the daytime propagation period (1200 to 2230). From 0500 to 0630, the phase increased 26 degrees; it then decreased 18 degrees by 0830, which was quite similar to the data presented in figures 2 through 4. However, just before the SRTP, the relative phase abruptly increased approximately 40 degrees; it then steadily decreased approximately 70 degrees from 0930 to 1100.

During 26 September (figure 6), the field strength amplitude decreased 4 dB from 0430 to 0630 and then increased 4 dB from 0630 to 0830. The amplitude dipped slightly (approximately 1 dB) at the beginning of the SRTP and then increased to the average daytime value by the end of the period. However, the

Table 7. Comparison of Minimum Nighttime Field Strength Amplitude Times With Maximum Nighttime Relative Phase Times

Date (1976)	Minimum Nighttime Field Strength Time (GMT)	Maximum Nighttime Relative Phase Time (GMT)	Time Difference (hours)
8/4	0800	--	--
8/5	0700-0730	--	--
8/18	0830	0800	0.5
9/10	0700	0630	0.5
9/11	0600-0630	0530	0.5-1.0
9/12	0600	0500	1.0
9/15	0600-0630	0600	0.0-0.5
9/18	0600-0630	0500	1.0-1.5
9/21	0830-0900	0730	1.0-1.5
9/22	0730	0630	1.0
9/23	0700-0730	0600-0630	1.0
9/24	0700	0600	1.0
9/25	0630-0700	0630	0.0-0.5
9/26	0630	0500	1.5
9/28	0630	0530-0600	0.5-1.0
9/29	0630	0530	1.0
9/30	0600	0500	1.0
10/1	0500	0400	1.0
10/2	0630	0530	1.0
10/5	0630	0630	0.0
10/6	0800-0830	0800	0.0-0.5
10/8	0630	0600-0630	0.0-0.5
10/9	0700	0630	0.5
10/28	0230	0200	0.5
10/31	0600	0500	1.0
11/12	0900	0800	1.0
11/22	0730	0600	1.5
11/25	0830-0900	0800	0.5-1.0
12/5	1000-1030	0930	0.5-1.0
12/8	0700	--	--
12/9	0800	--	--
12/18	0330	0230	1.0
12/19	0630	0600	0.5
12/28	0630	0600	0.5
Average	∿ 0700	∿ 0600	∿ 1 hour

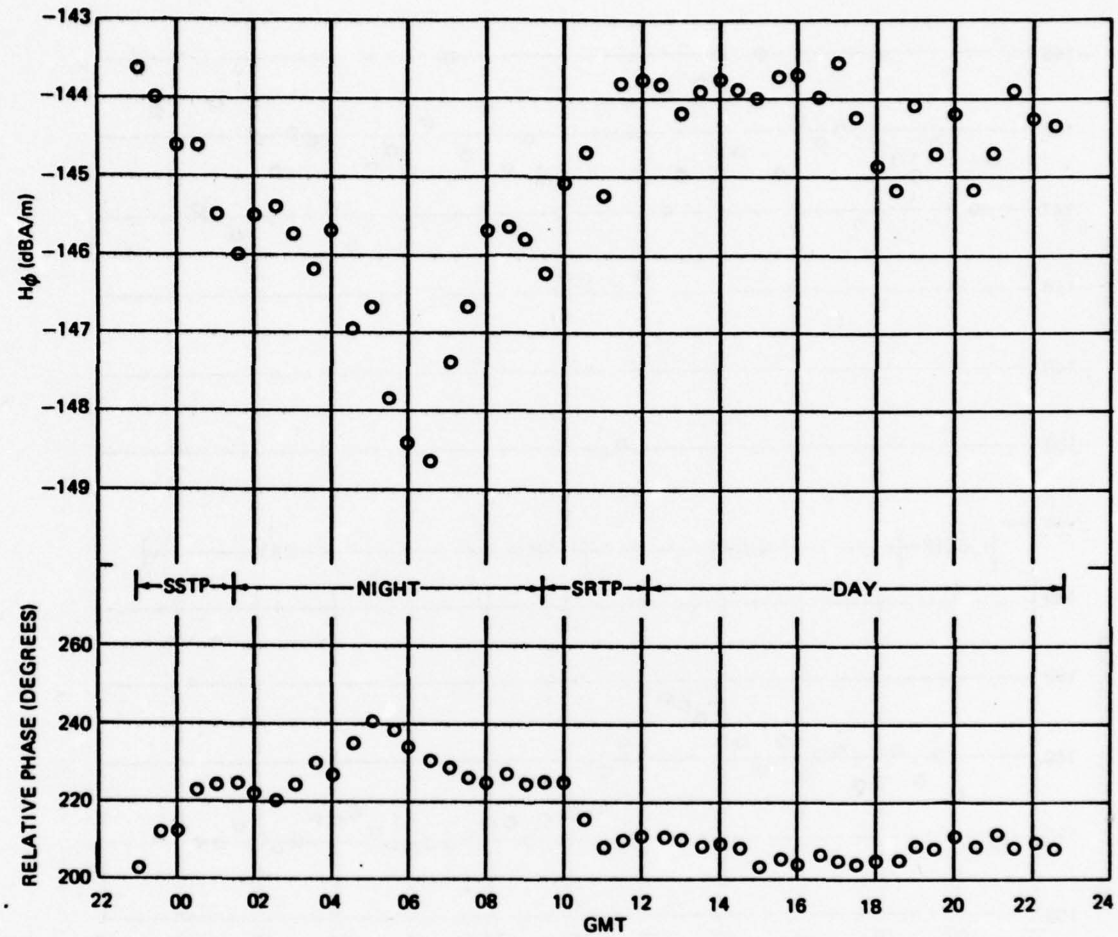

Figure 2. 18 September Connecticut Field Strengths Versus GMT (ψ = 21°)

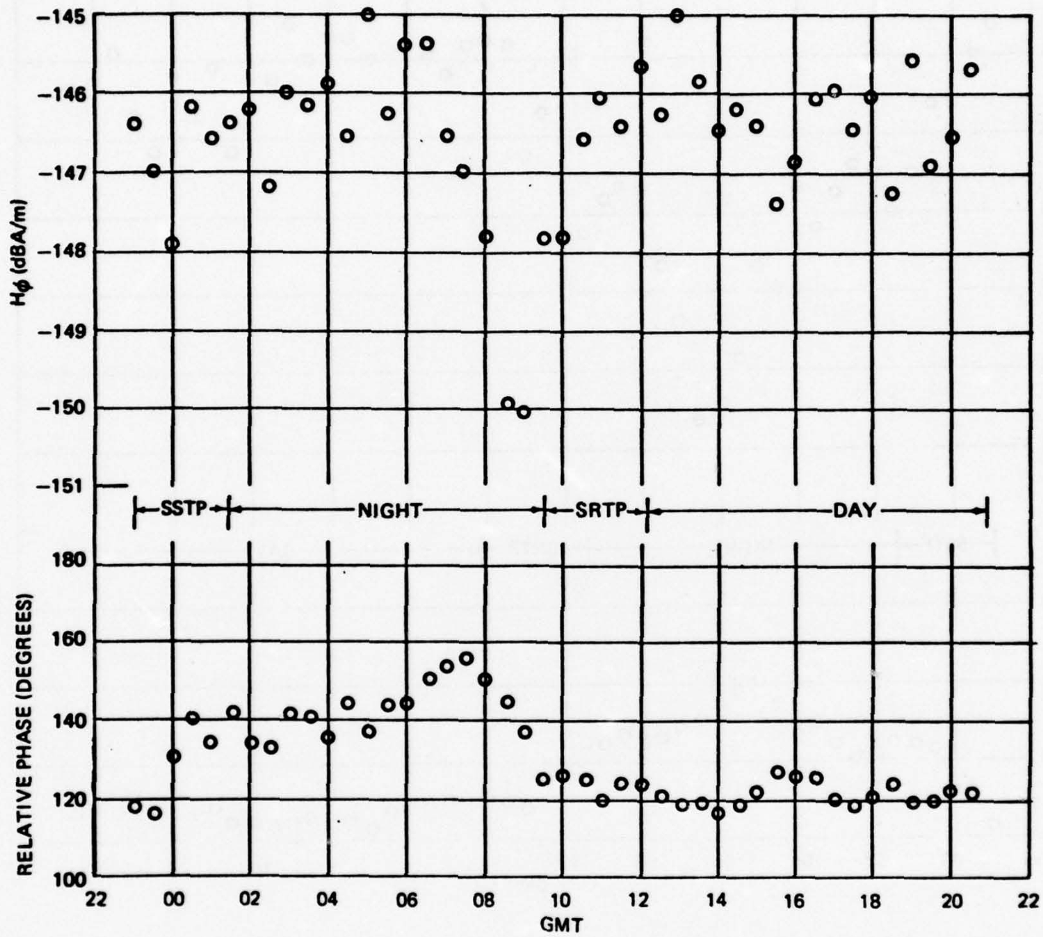

Figure 3. 21 September Connecticut Field Strengths Versus GMT (ψ = 21°)

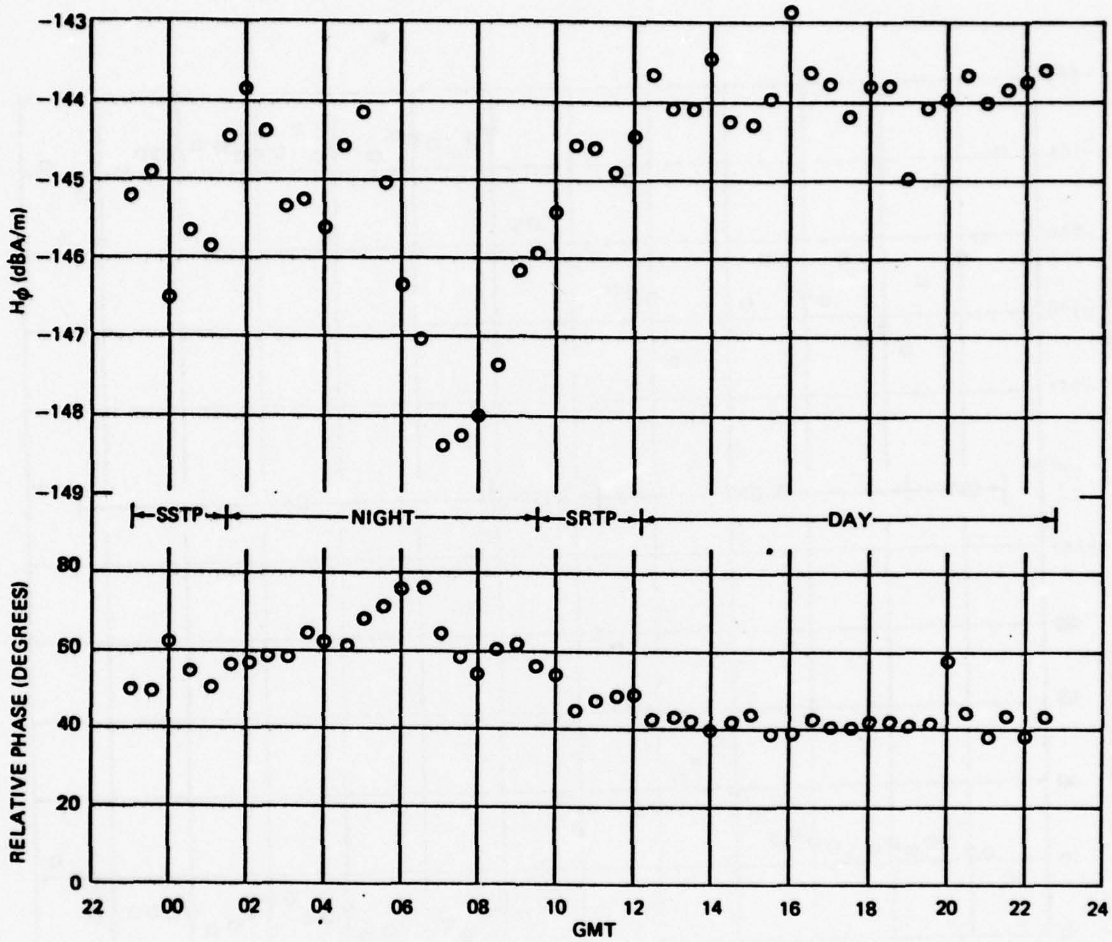

Figure 4. 23 September Connecticut Field Strengths Versus GMT (ψ = 21°)

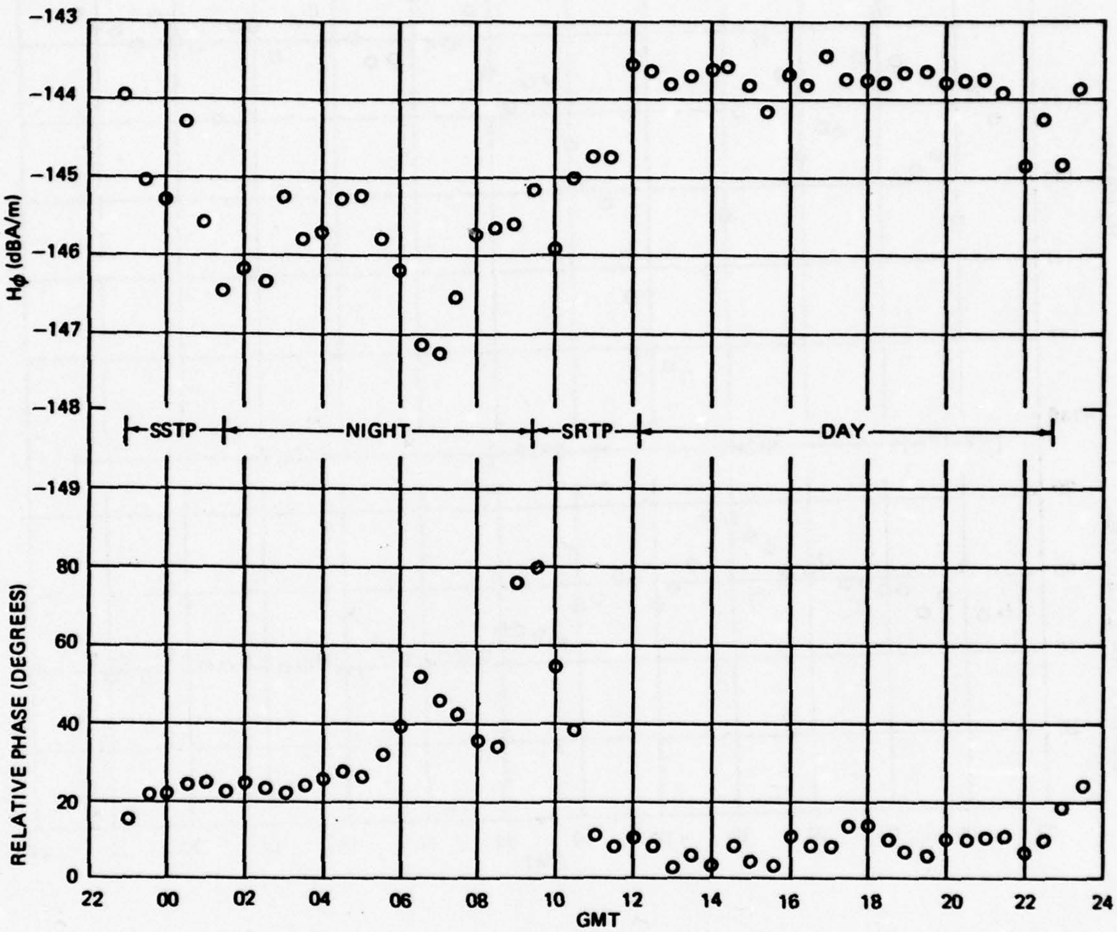

Figure 5. 25 September Connecticut Field Strengths Versus GMT (ψ = 21°)

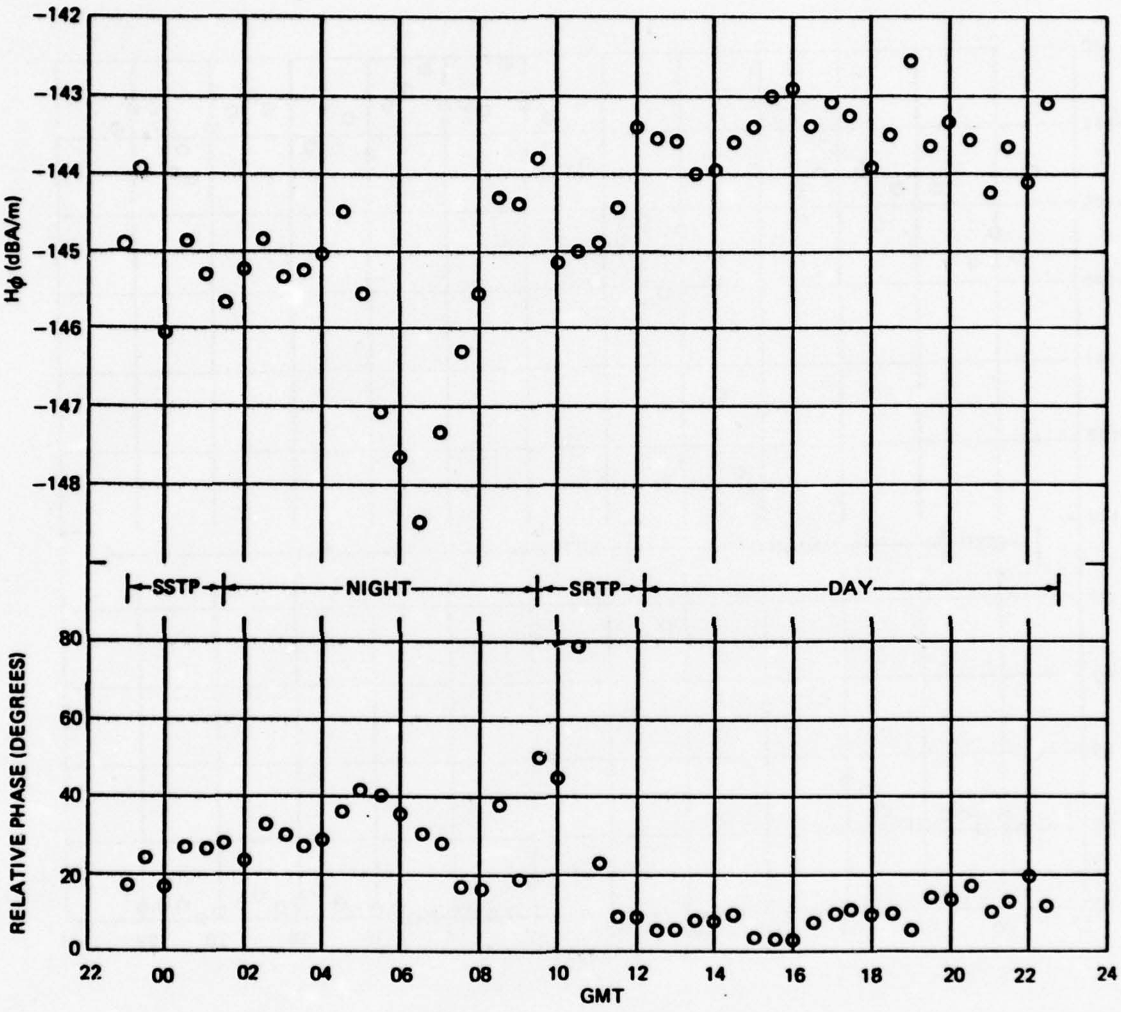

Figure 6. 26 September Connecticut Field Strengths Versus GMT (ψ = 21°)

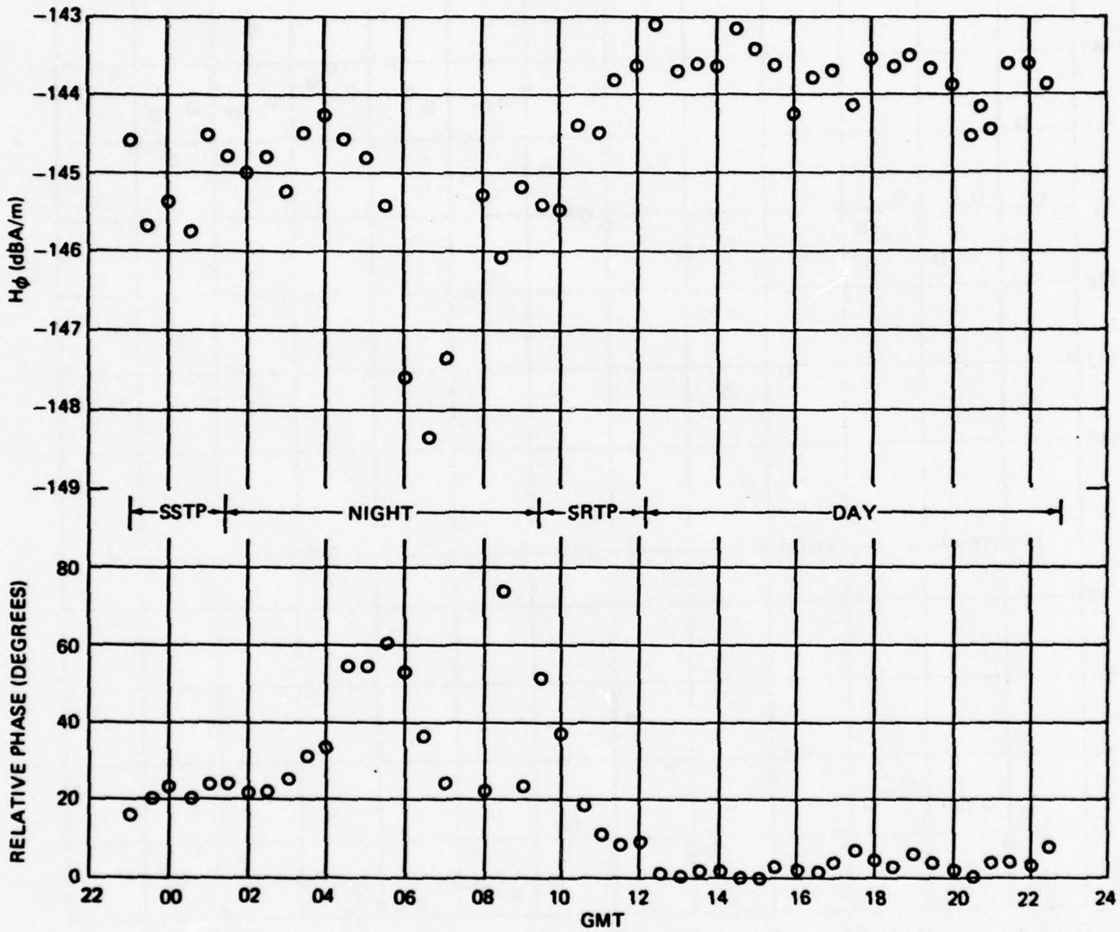

Figure 7. 29 September Connecticut Field Strengths Versus GMT (ψ = 21°)

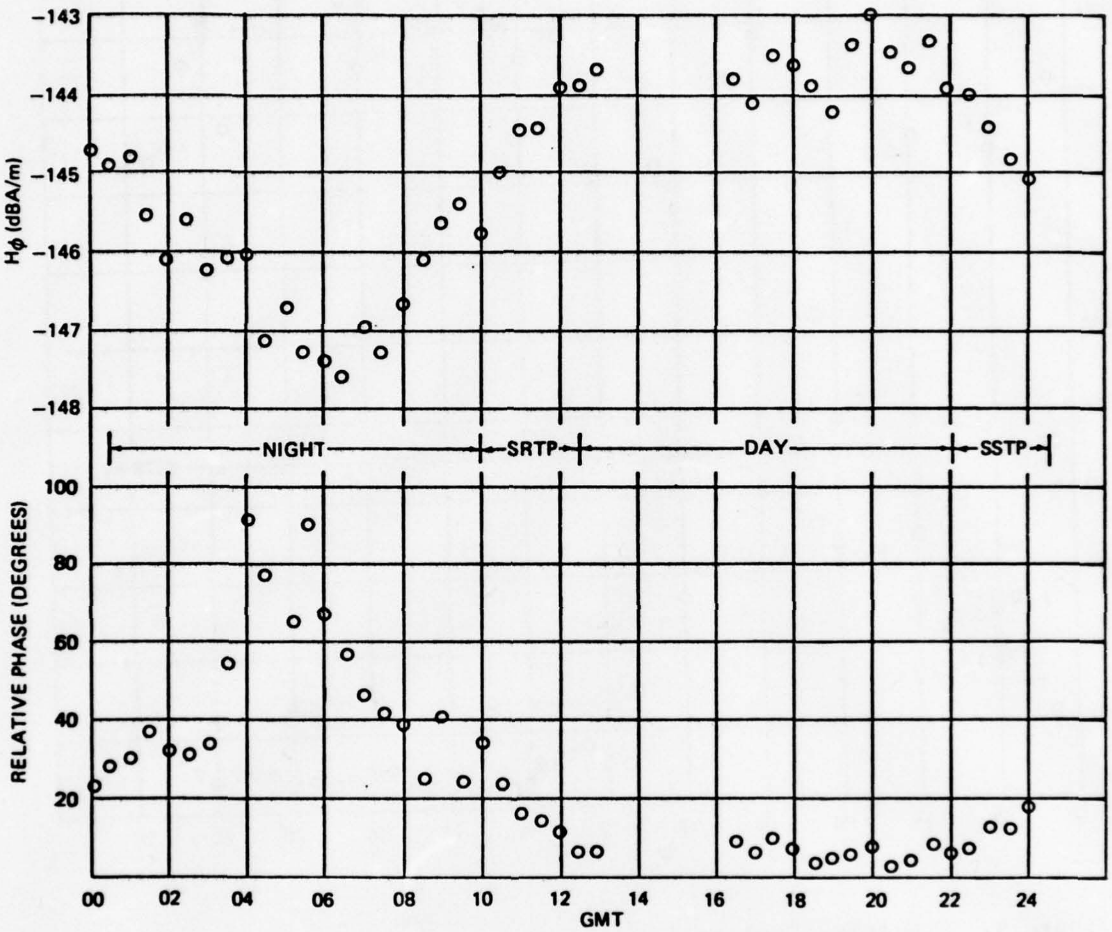

Figure 8. 2 October Connecticut Field Strengths Versus GMT (ψ = 21°)

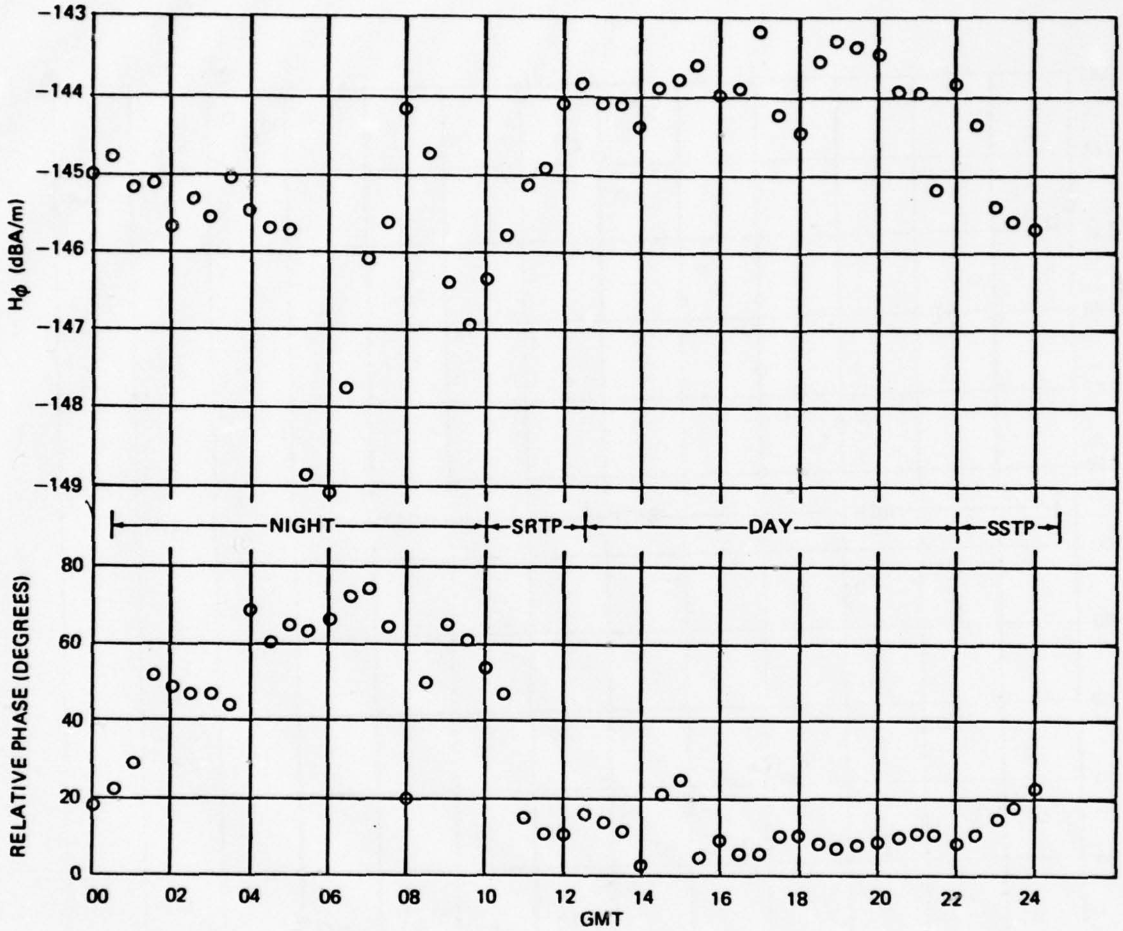

Figure 9. 3 October Connecticut Field Strengths Versus GMT (ψ = 21°)

relative phase increased, and then decreased by approximately 60 to 70 degrees during the SRTP.

On 29 September (figure 7), the field strength amplitude decreased 4 dB from 0400 to 0630, and then increased 5 dB by 1200. The amplitude steadily increased 2 dB during the SRTP, with little sample-to-sample variation. On the other hand, the nighttime relative phase increased approximately 40 degrees from 0230 to 0530, and then decreased approximately 40 degrees by 0800. The relative phase suddenly increased approximately 50 degrees just before the SRTP, and then steadily decreased approximately 70 degrees during the SRTP.

During the night of 2 October (figure 8), the field strength amplitude steadily decreased 3 dB from 0000 to 0600, and then steadily increased 2 dB from 0600 to 1000, once again with little sample-to-sample variation. However, during this same time period, the nighttime relative phase increased and then decreased by approximately 70 degrees, which is more than 3 times the normal 22-degrees night-to-day relative phase difference (see table 6).

On 3 October (figure 9), both the amplitude and relative phase variations were abnormal. The nighttime amplitude was relatively constant until around 0500, when it abruptly decreased approximately 3 dB; it then increased approximately 5 dB from 0600 to 0800, decreased approximately 3 dB from 0800 to 0930, and then increased to the daytime average value by the end of the SRTP. The relative phase increased approximately 50 degrees from 0000 to 0700, decreased approximately 50 degrees by 0800, increased approximately 40 degrees by 0900, and then decreased approximately 50 degrees by 1100.

Some examples of SSTP anomalies are plotted against GMT in figures 10 and 11. On 12 October (figure 10), the SSTP field strength amplitude steadily decreased approximately 3.5 dB from 2200 to 0030, reaching a value approximately 1.5 dB below the nighttime average. The relative phase increased 35 degrees from 2200 to 2400, and then decreased 16 degrees by 0100.

On 13 October (figure 11), the SSTP amplitude steadily decreased approximately 4 dB from 2200 to 0030, reaching a minimum value approximately 2 dB below the nighttime average. The relative phase increased by 36 degrees from 2200 to 2400 and decreased 16 degrees by 0100.

A comparison of the data presented in figures 10 and 11 with the data plotted in figures 5 through 9 reveals that, to date, the relative phase fluctuations are much more severe during the SRTP than during the SSTP. However, the SRTP amplitudes are always higher than the nighttime minimum values, whereas some of the SSTP amplitudes are lower than those measured during the night. Nevertheless, contrary to the behavior of very low frequency (VLF) radio waves, no large-scale field strength amplitude nulls were observed during the sunrise or sunset transition periods.

During the last 7 years of Connecticut measurements, significantly more severe field strength variations have been measured during the night than during the day. That is why the daytime field strength anomalies presented in figures 12 and 13 were totally unexpected.

On 23 August (figure 12), the daytime field strength amplitude decreased approximately 7.5 dB from 1730 to 2200 and then increased approximately 6 dB

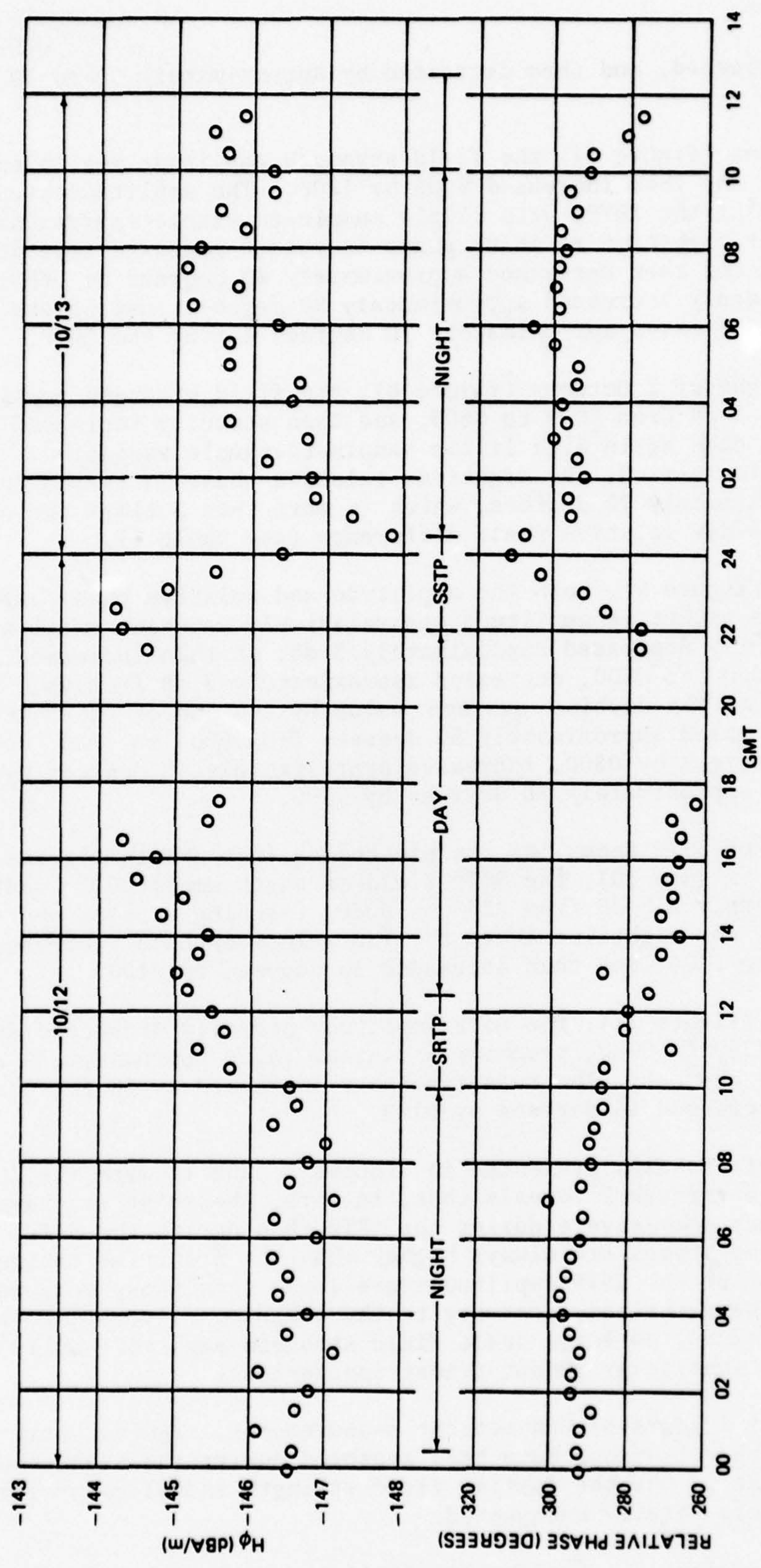

Figure 10. 12 and 13 October Connecticut Field Strengths Versus GMT (ψ = 110°)

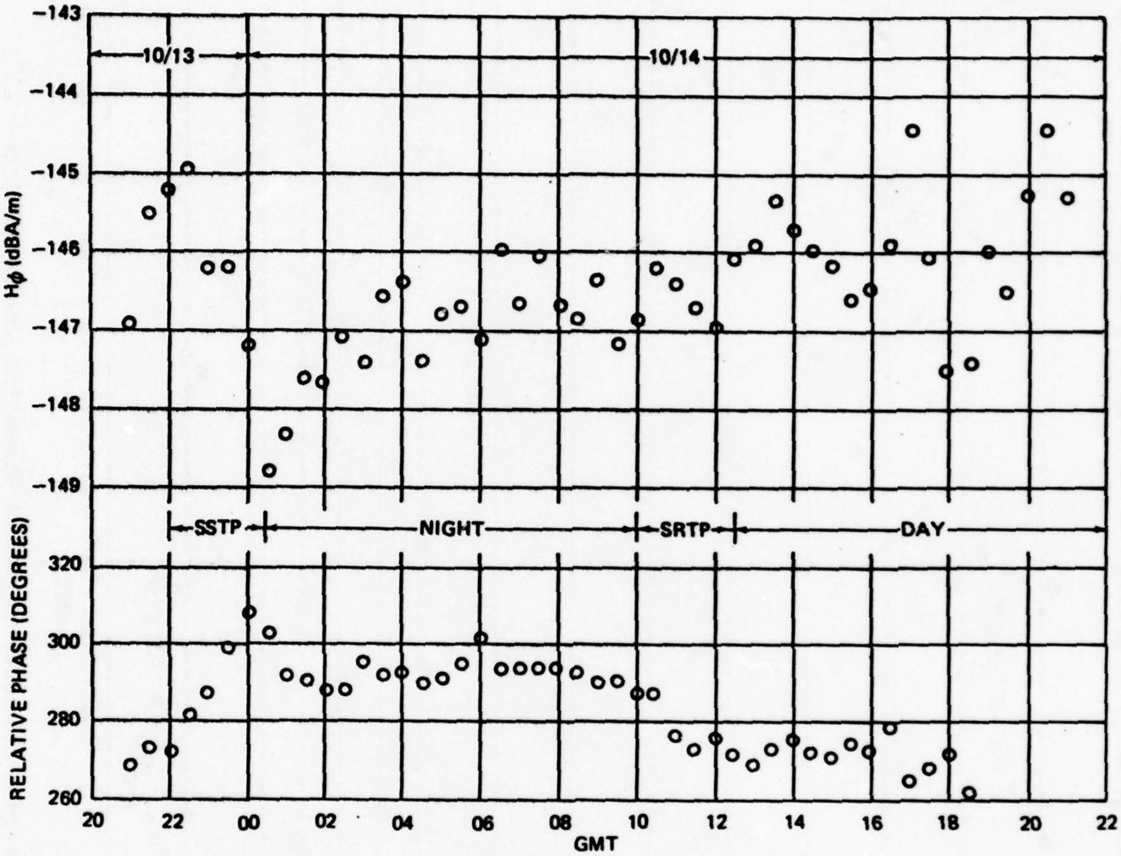

Figure 11. 13 and 14 October Connecticut Field Strengths Versus (GMT (ψ = 110°)GMT (ψ = 110°)

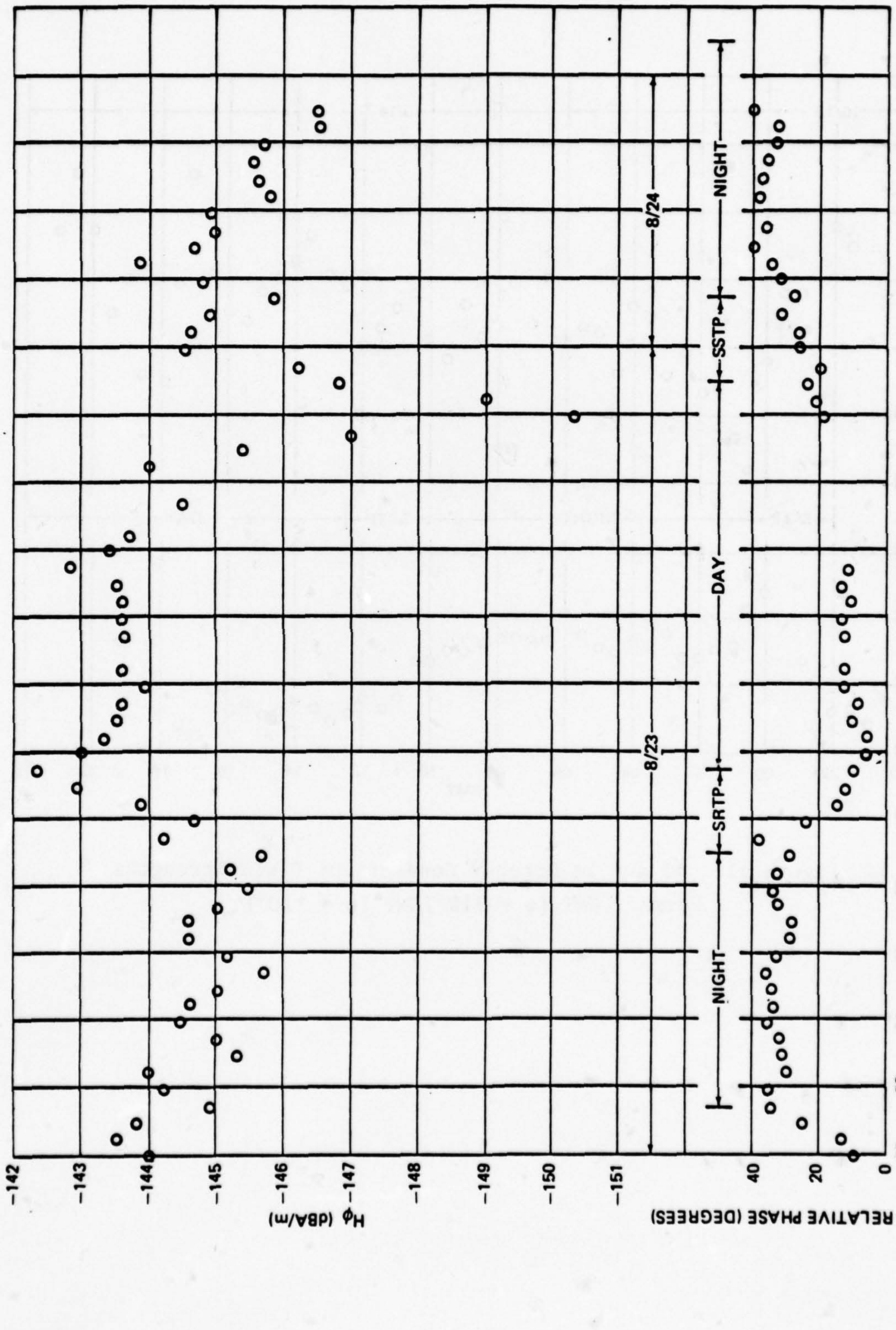

Figure 12. 23 and 24 August Connecticut Field Strengths Versus GMT (ψ = 21°)

from 2200 to midnight. However, the relative phase only increased by approximately 10 degrees. The next day (figure 13), the daytime field strength decreased approximately 7 dB from 1330 to 2100, and then increased by approximately 15 degrees, whereas the relative phase decrease from 2100 to 2300 was 18 degrees.

Figure 14 plots field strengths against GMT for 18 and 19 December. During 18 December, the nighttime amplitude decreased approximately 5 dB from 0200 to 0330; it then steadily increased approximately 7 dB by 1400. This 7 dB night-to-day variation is comparable to the largest night-to-day variations measured in Connecticut to date (on 25 and 26 January and 19 and 20 March 1974).[5] It also is comparable to the late daytime variations measured during 23 and 24 August (figures 12 and 13). On 18 December, the relative phase increased by approximately 30 degrees from 0130 to 0230, and then decreased by approximately 30 degrees from 0230 to 0400.

The field strengths measured during three days in late October are presented in figures 15 through 17. The late October measurement period is highlighted by the "Halloween effect." This effect has been observed for the last 7 consecutive years between 27 October and 1 November. It is marked by an average drop in field strength of from 2 to 6 dB, relative to the preceding and following nights.[1-7] The effect has been observed in both the 40- to 50- and 70- to 80-Hz frequency bands.

The Halloween effect may well be related to the famous "November effect." Early observations of VLF waves transmitted from North America to England showed marked decreases in signal strength near the end of October and in early November (Round et al.).[19] Furthermore, near the end of October, VLF and low frequency (LF) radio waves received over paths of less than 1.2 Mm in western Europe showed large departures (both increases and decreases) in signal strengths from that of their summer values.[20] This so-called November effect has since been identified as part of the summer-to-winter change in the D-region and has been observed as an increase in signal strength of VLF and LF waves over short (less than 600 km) paths.[21-23] Thomas has recently used recordings of VLF, LF, and medium-frequency (MF) radio waves, propagated over short paths, to examine the times of onset of the summer-to-winter change in the D-region over central Europe during 1970-72.[24] These times are found to be delayed by about a month on the reversal in the mean zonal circulation in the stratosphere. The delay becomes longer with greater height in the D-region.

Referring to figures 15 through 17, we see that the nighttime field strengths measured on 30 and 31 October were 2 to 3 dB lower than those measured on 29 October. The nighttime field strengths may have been even lower on 30 October, but we cannot know for certain because the WTF transmitter was off the air from 0800 to 1000.

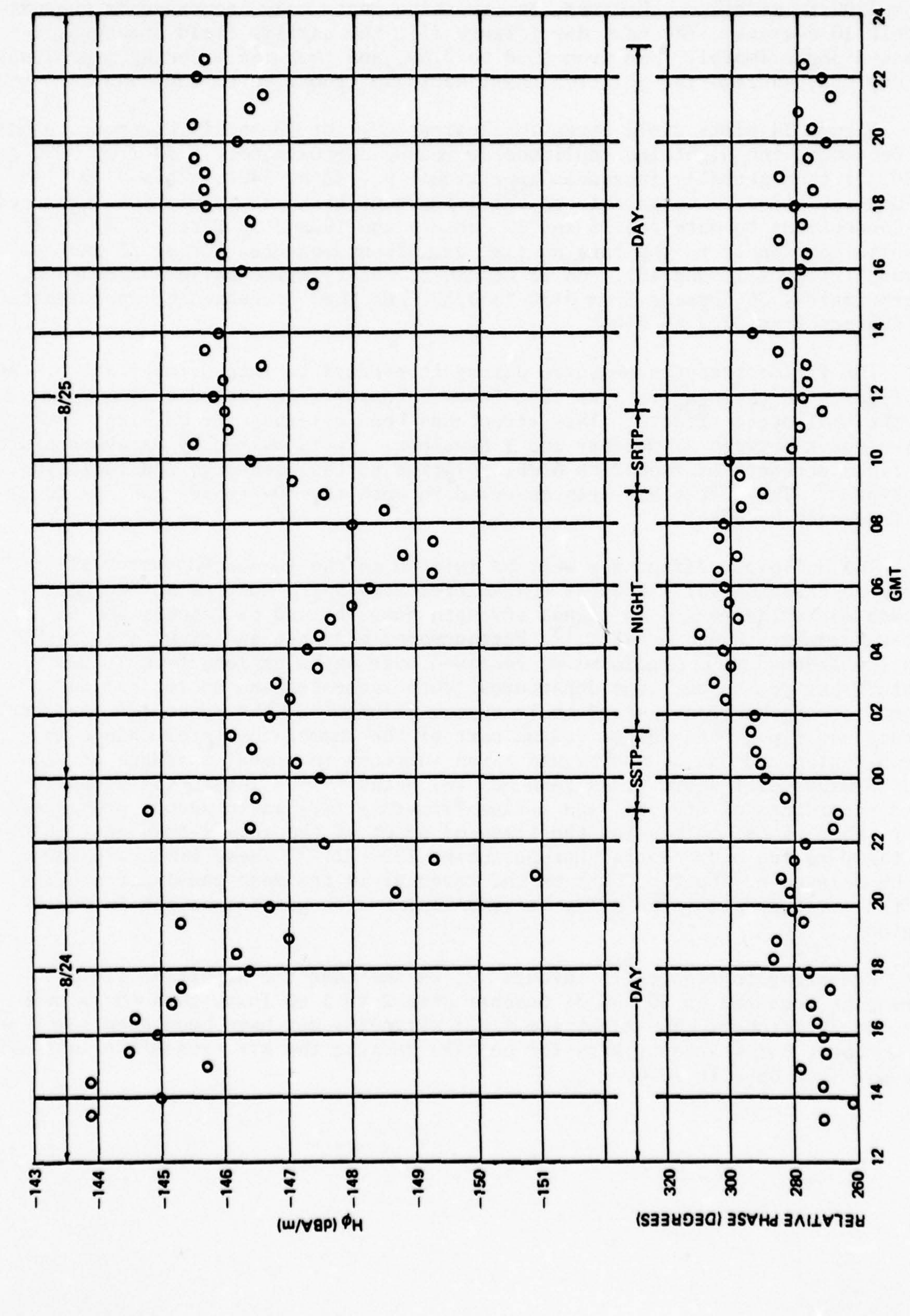

Figure 13. 24 and 25 August Connecticut Field Strengths Versus GMT (ψ = 110°)

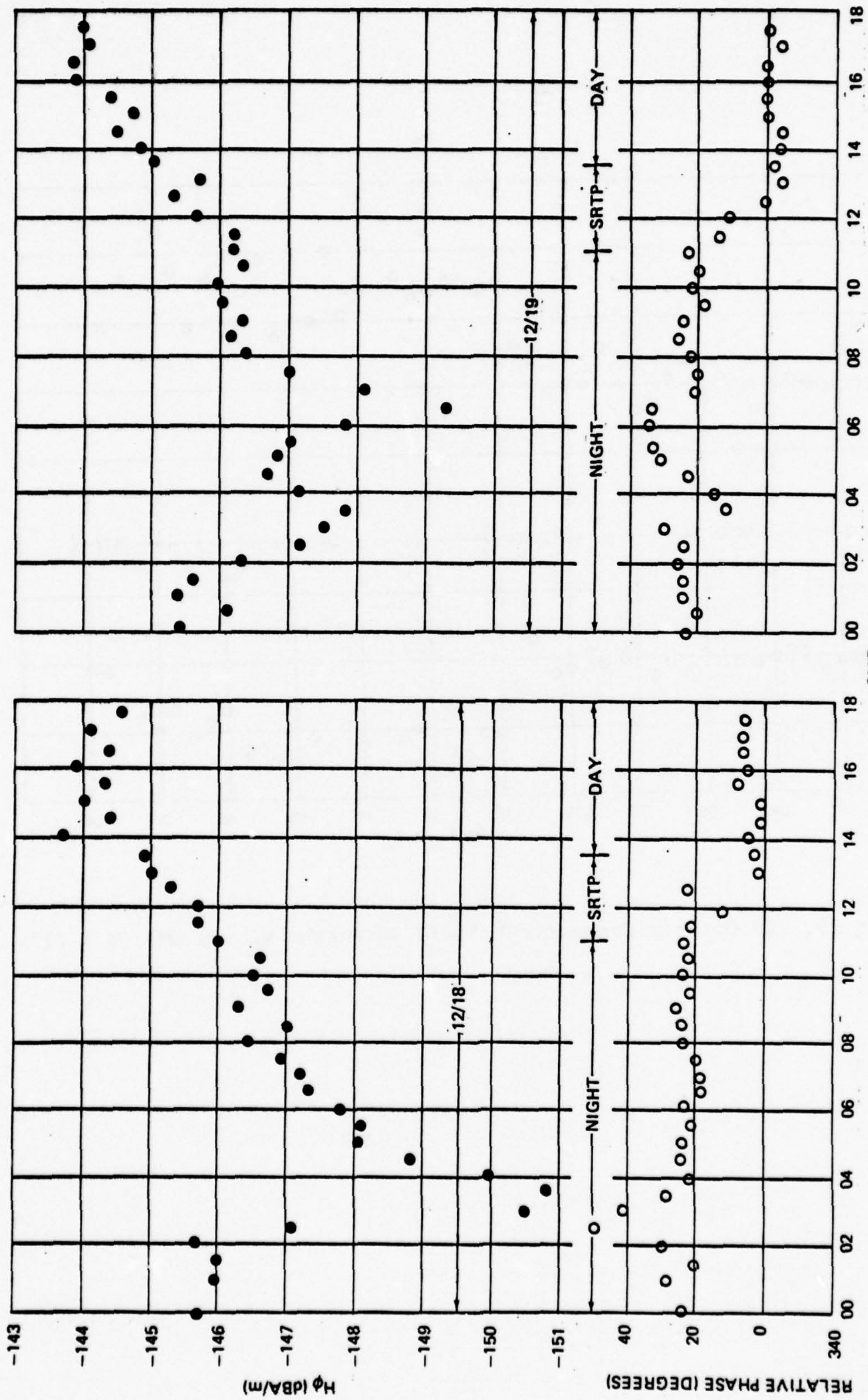

Figure 14. 18 and 19 December Connecticut Field Strengths Versus GMT (ψ = 21°)

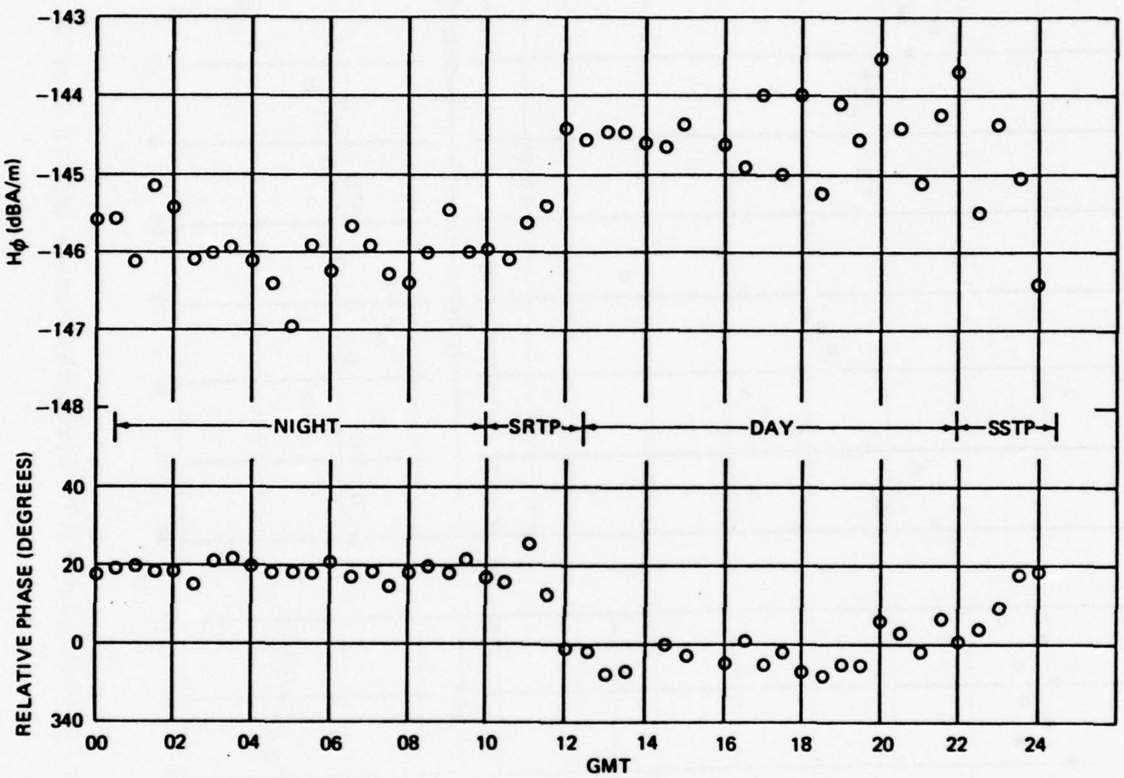

Figure 15. 29 October Connecticut Field Strengths Versus GMT (ψ = 21°)

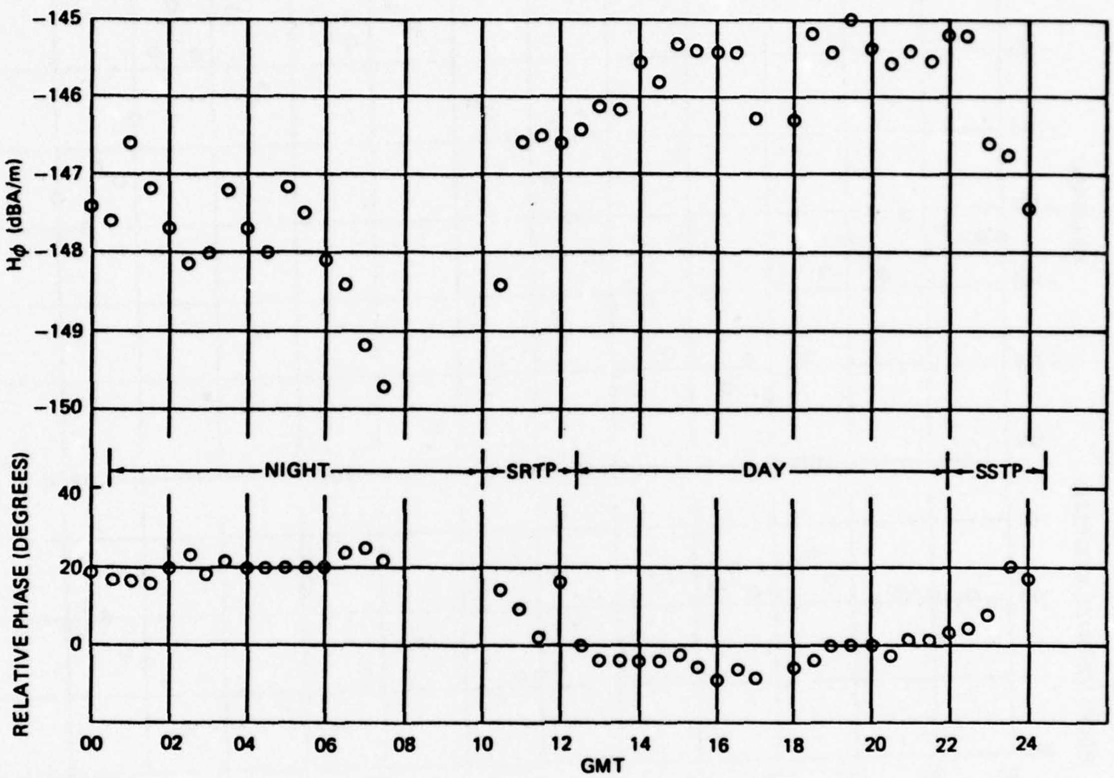

Figure 16. 30 October Connecticut Field Strengths Versus GMT (ψ = 21°)

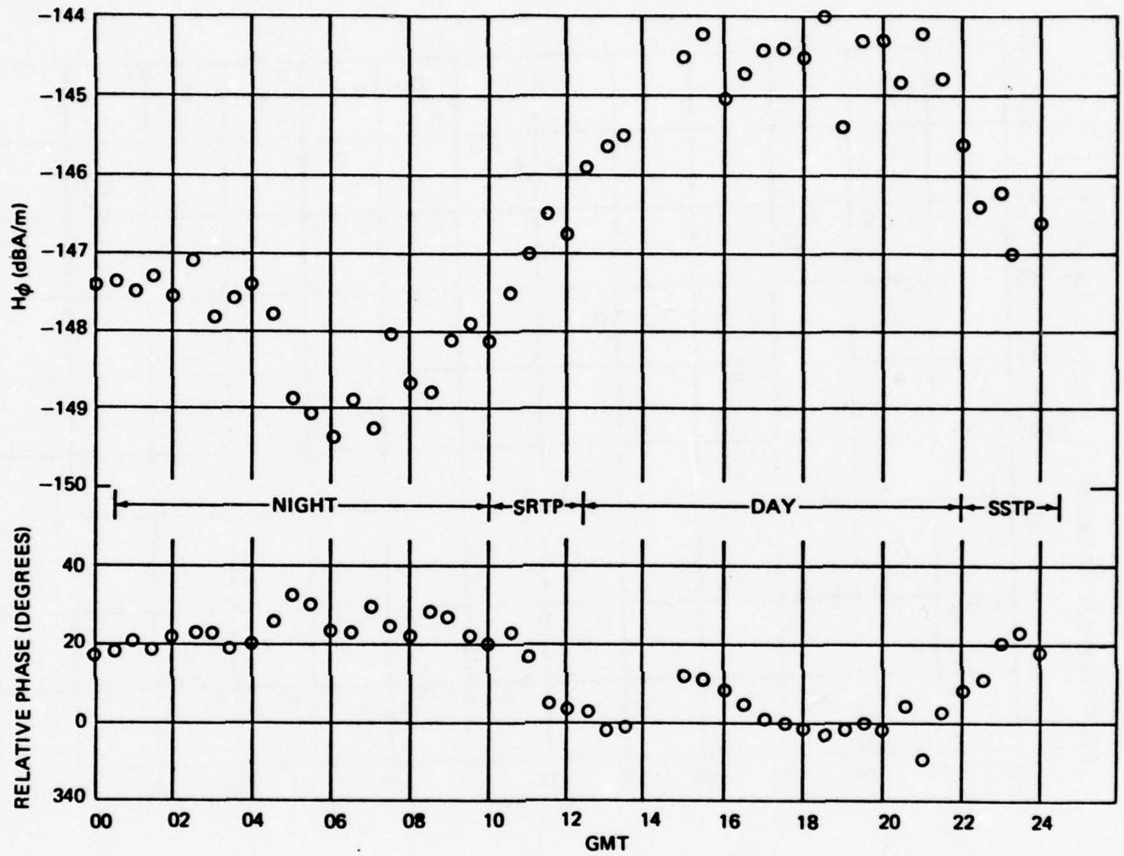

Figure 17. 31 October Connecticut Field Strengths Versus GMT (ψ = 21°)

DISCUSSION

Because some previous ELF field strength variations appeared to be correlated with geomagnetic activity, it would be of interest to compare the 1976 Connecticut measurements with geomagnetic activity.[5,15,16] Presented in figures 18 and 19 are daily comparisons of the normalized minimum field strengths (measured during a 1 hour period) with the geomagnetic A_k index for Fredricksburg, VA. The minimum values are nighttime data except for the 23 and 24 August data, when abnormally low daytime field strengths were measured (see figures 12 and 13). The normalization factor (-145.7 dBA/m) is the average value of the nighttime field strength measured in Connecticut from 1970 - 74.[5] Different WTF phasings have also been accounted for (i.e., the reference ψ is 21 degrees).

It is readily apparent from figures 18 and 19 that during August to December 1976, increases in geomagnetic activity were usually accompanied by decreases in the minimum nighttime field strength measured at the Connecticut site. The principal exceptions to this trend occurred during 16 - 18 October and on 29 December (figure 19); however, the average daytime field strength measured on these dates was approximately 1 dB lower than normal. Furthermore, the $\Delta\phi$ value measured during 29 December was only 12 degrees, which was 8 degrees less than the monthly average.

It is also observed from figures 18 and 19 that the time period between the lowest measured minimum nighttime field strengths is approximately 25 to 28 days. This repetition period is nearly equal to the solar rotation period of 27 days.

During many measurement days (see table 7 and the appendix), the nighttime field strength amplitude was observed to reach a minimum between 0600 and 0800. Intuitively, one would think that when the signal level decreases, the noise level would also decrease. In a recent report, we compared the field strength, atmospheric noise, and SNR behavior for 33 nights during which the field strength varied considerably during the nighttime measurement period, or from night to night.[7] We found that large decreases in signal strength usually were not accompanied by large changes in atmospheric noise levels. The average signal decrease was approximately 4.5 dB and the average noise decrease was approximately 0 dB, resulting in an average SNR decrease of approximately 4.5 dB.

Table 8 presents a comparison of nighttime field strength, effective atmospheric noise, and SNR behavior during 17 nights in 1976. Again we find that large decreases in signal strength are not accompanied by large decreases in effective atmospheric noise levels. The average signal decrease was approximately 3.7 dB and the average effective noise decrease was approximately 0.6 dB, resulting in an average SNR decrease of approximately 3 dB.

The largest SNR decreases observed during 1976 occurred during the late afternoon on 23 and 24 August (figures 12 and 13). The field strengths decreased by approximately 6 dB and the effective noise increased by approximately 3 dB, resulting in an SNR decrease of 9 dB.

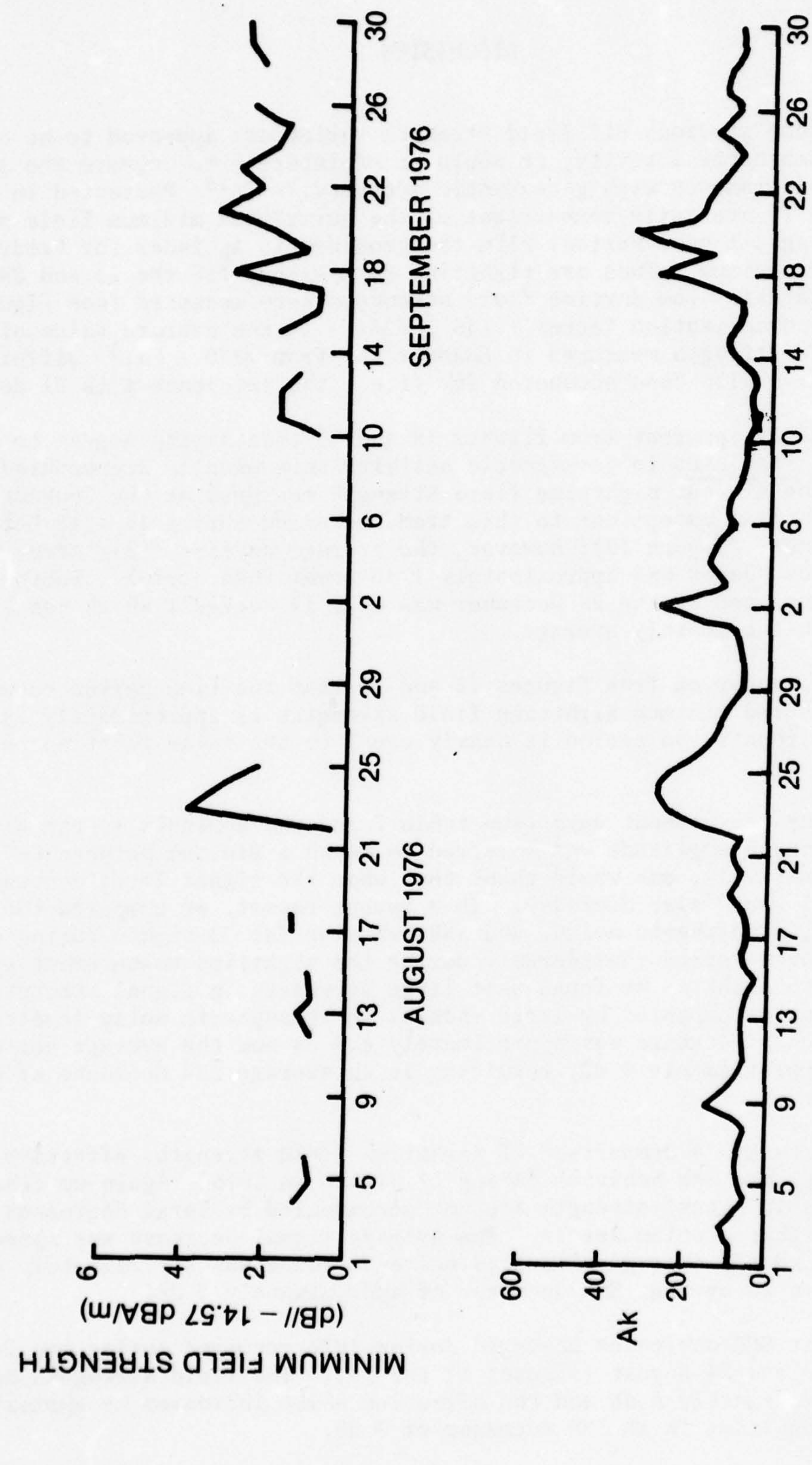

Figure 18. Daily Comparison of Minimum Nighttime Field Strength With Geomagnetic Behavior — August and September 1976

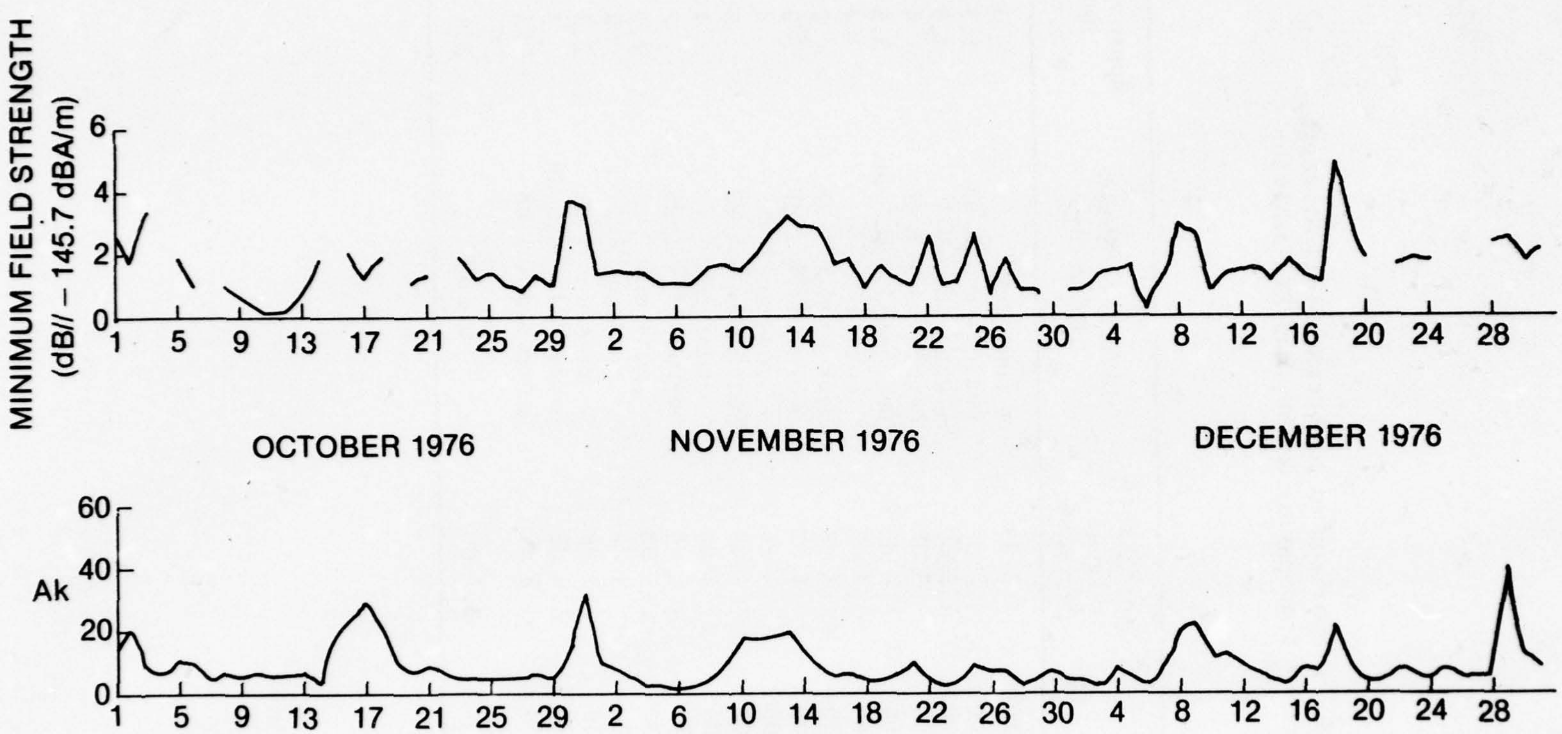

Figure 19. Daily Comparison of Minimum Nighttime Field Strength With Geomagnetic Behavior — October, November, and December 1976

Table 8. Comparison of Nighttime Field Strength, Effective Atmospheric Noise, and SNR Behavior

Date (1976)	Time (GMT)	Approximate Signal Decrease	Effective Noise Behavior	Approximate SNR Decrease
8/3	0400-0800	3 dB	∿ constant	3 dB
8/25	0100-0700	4.5 dB	Decreased ∿ 3 dB	1.5 dB
9/12	0400-0600	2.5 dB	∿ constant	2.5 dB
9/21	0600-0900	5 dB	Decreased ∿ 1 dB	4 dB
9/23	0500-0800	4 dB	Decreased ∿ 0.5 dB	3.5 dB
9/26	0400-0700	4 dB	∿ constant	4 dB
9/28	0400-0700	3 dB	Decreased ∿ 1 dB	2 dB
9/29	0400-0700	4 dB	Decreased ∿ 1 dB	3 dB
9/30	0400-0600	4 dB	∿ constant	4 dB
10/1	0300-0500	4 dB	Decreased ∿ 1 dB	3 dB
10/3	0400-0600	4 dB	∿ constant	4 dB
10/20	0430-0830	3 dB	Decreased ∿ 1 dB	2 dB
10/30	0500-0730	2.5 dB	∿ constant	2.5 dB
11/12	0600-0900	4 dB	∿ constant	4 dB
11/22	0230-0800	3.5 dB	Decreased ∿ 1 dB	2.5 dB
12/8	0400-0700	3.5 dB	Decreased ∿ 0.5 dB	3 dB
12/18	0200-0330	5 dB	Decreased ∿ 1 dB	4 dB
Average Decrease		3.7 dB	0.6 dB	3.1 dB

The probable reason that signal and effective noise decreases are not correlated is that the signal path is a point-to-point path (i.e., highly directional), whereas the atmospheric-noise-to-Connecticut path is essentially nondirectional.

CONCLUSIONS

The horizontal magnetic field strengths measured in Connecticut during 1976 again demonstrated that ELF nighttime propagation is much more variable than ELF daytime propagation.

It has been shown that the nighttime field strength amplitude usually reached a minimum around 0600 to 0800 GMT and that the nighttime relative phase reached a maximum about an hour earlier. The time of the lowest nighttime field strengths (0600 to 0800 GMT) coincided with the farthest southern displacement of the auroral oval, and presumably indicated the time at which precipitated energetic electrons reached their southernmost extent in the middle latitudes.

It was observed that increases in geomagnetic activity were usually accompanied by decreases in the minimum nighttime field strength. Furthermore, the repetition period between the lowest measured minimum nighttime field strengths was nearly equal to the (27 day) solar rotation period.

The average relative phase difference between daytime and nighttime propagation conditions was 22 degrees, which corresponds to a relative phase velocity difference $\Delta(c/v)$ of 0.15. This value is in excellent agreement with previous measurements. Occasionally, relative phase changes during pure nighttime and SRTP propagation conditions were greater than changes associated with the sunrise-sunset terminators crossing the transmitter or receiver locations.

The Halloween effect was observed for the seventh consecutive year. Furthermore, it was determined that large decreases in signal strength were not usually accompanied by large decreases in effective noise levels.

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Appendix

DAILY FIELD-STRENGTH PLOTS

The daily field strength values (both amplitude and relative phase) measured in Connecticut from August through December 1976 are plotted against GMT in this appendix. The WTF antenna phasing angle ψ was 21 degrees during most of this time period. For each of these plots, the effective integration time per sample was 1,792 seconds, or approximately 30 minutes, and the average SNR was 22 to 27 dB. Each 1,792-second effective integration time sample is an average of two 896-second samples, or of one 1,792-second actual integration time sample. The ending times (GMT) of the two 896-second samples that comprise each 1,792-second plotted effective integration time sample are listed in table A-1.

The August data are presented in figures A-1 through A-8, the September data are presented in figures A-9 through A-28, and the October data are presented in figures A-29 through A-47. The November data are plotted in figures A-48 through A-62, and the December data are presented in figures A-63 through A-76.

During most of the measurement days, the 80-percent confidence interval for the pure nighttime or pure daytime propagation condition mean data was approximately $\pm$ 0.3 dB. Sample-to-sample variability in excess of this confidence interval is regarded as significant.

Most of the August data exhibited more sample-to-sample variability than occurred during the rest of the measurement period. This was because the effective noise was higher during August.[12] Thus the 80-percent confidence interval for the August mean data was approximately $\pm$ 0.6 dB.

On 9 October (figure A-35), daytime signal strengths varied considerably from 1600 to 2100 because of the extremely high effective noise values occurring during this period.[12]

From 10 to 17 November (figures A-54 to A-56), the field strength values also exhibited considerable sample-to-sample variations. The reason for these variations was that the measured effective noise was approximately 10 dB higher than normal because of local interference at the Fishers Island, NY, receiving site.

Table A-1. 896-Second Sample Ending Times (GMT) Comprising Each 1,792-Second Sample Plotted Time

1,792-Second Sample Plotted Time	896-Second Sample Ending Times	1,792-Second Sample Plotted Time	896-Second Sample Ending Times
0000	0014, 0029	1200	1211, 1226
0030	0044, 0059	1230	1241, 1256
0100	0114, 0129	1300	1311, 1326
0130	0144, 0159	1330	1341, 1356
0200	0214, 0229	1400	1411, 1426
0230	0244, 0259	1430	1441, 1456
0300	0314, 0329	1500	1510, 1525
0330	0344, 0358	1530	1540, 1555
0400	0413, 0428	1600	1610, 1625
0430	0443, 0458	1630	1640, 1655
0500	0513, 0528	1700	1710, 1725
0530	0543, 0558	1730	1740, 1755
0600	0613, 0628	1800	1810, 1825
0630	0643, 0658	1830	1840, 1854
0700	0713, 0728	1900	1909, 1924
0730	0742, 0757	1930	1939, 1954
0800	0812, 0827	2000	2009, 2024
0830	0842, 0857	2030	2039, 2054
0900	0912, 0927	2100	2109, 2124
0930	0942, 0957	2130	2139, 2154
1000	1012, 1027	2200	2209, 2224
1030	1042, 1057	2230	2238, 2253
1100	1112, 1126	2300	2308, 2323
1130	1141, 1156	2330	2338, 2353

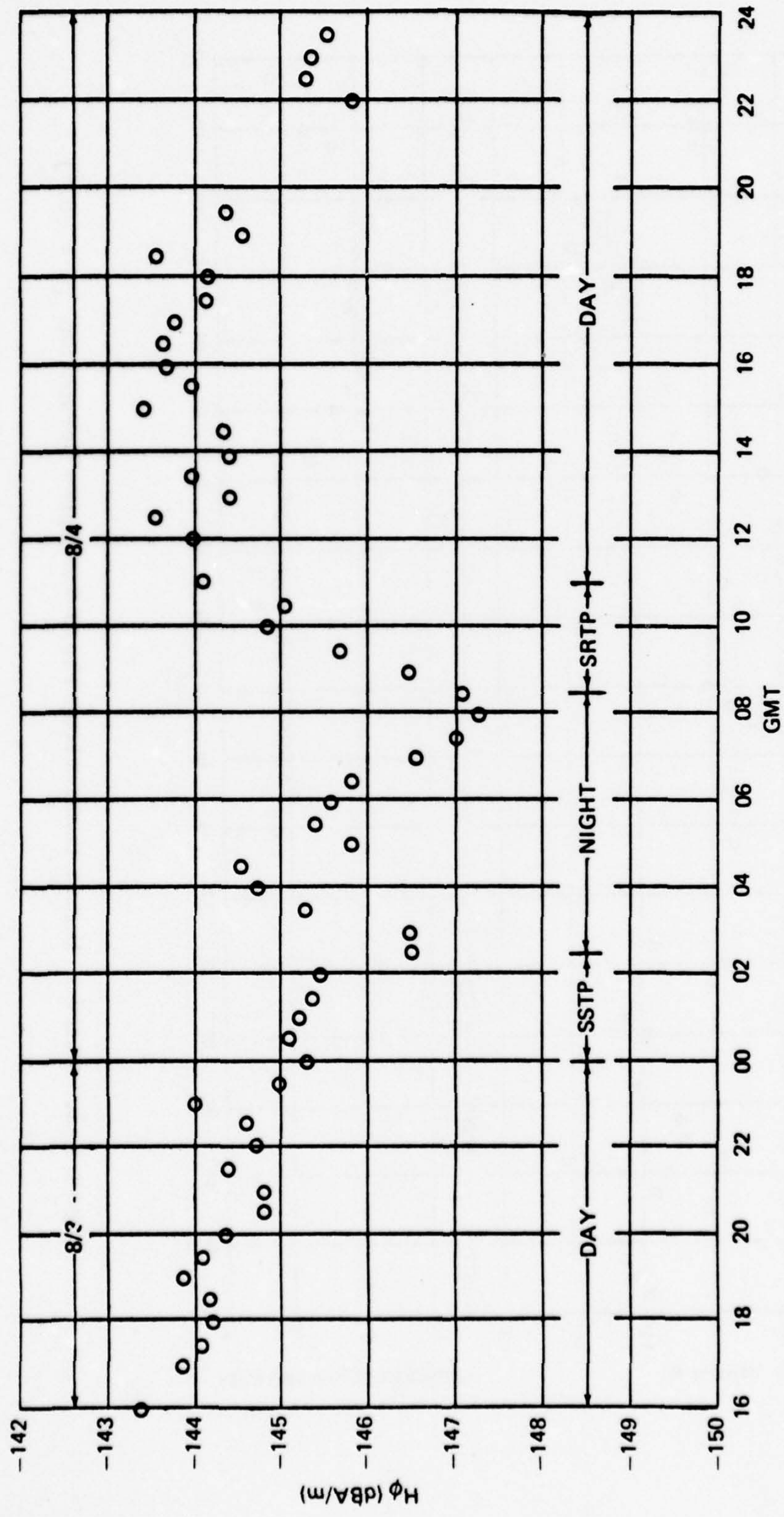


Figure A-1. 3 and 4 August Connecticut Field Strengths Versus GMT (ψ = 207°)

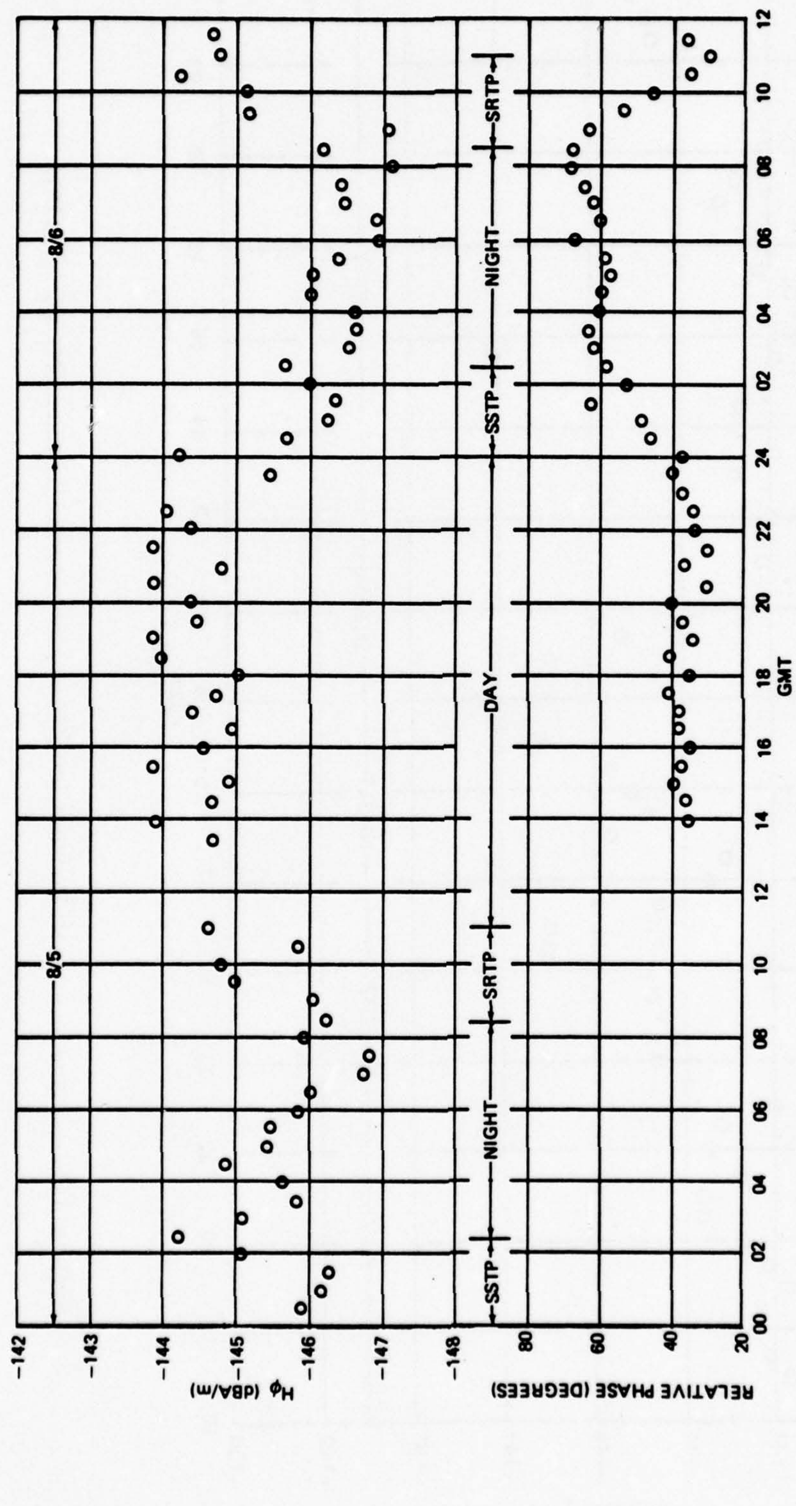


Figure A-2. 5 and 6 August Connecticut Field Strengths Versus GMT (ψ = 207°)

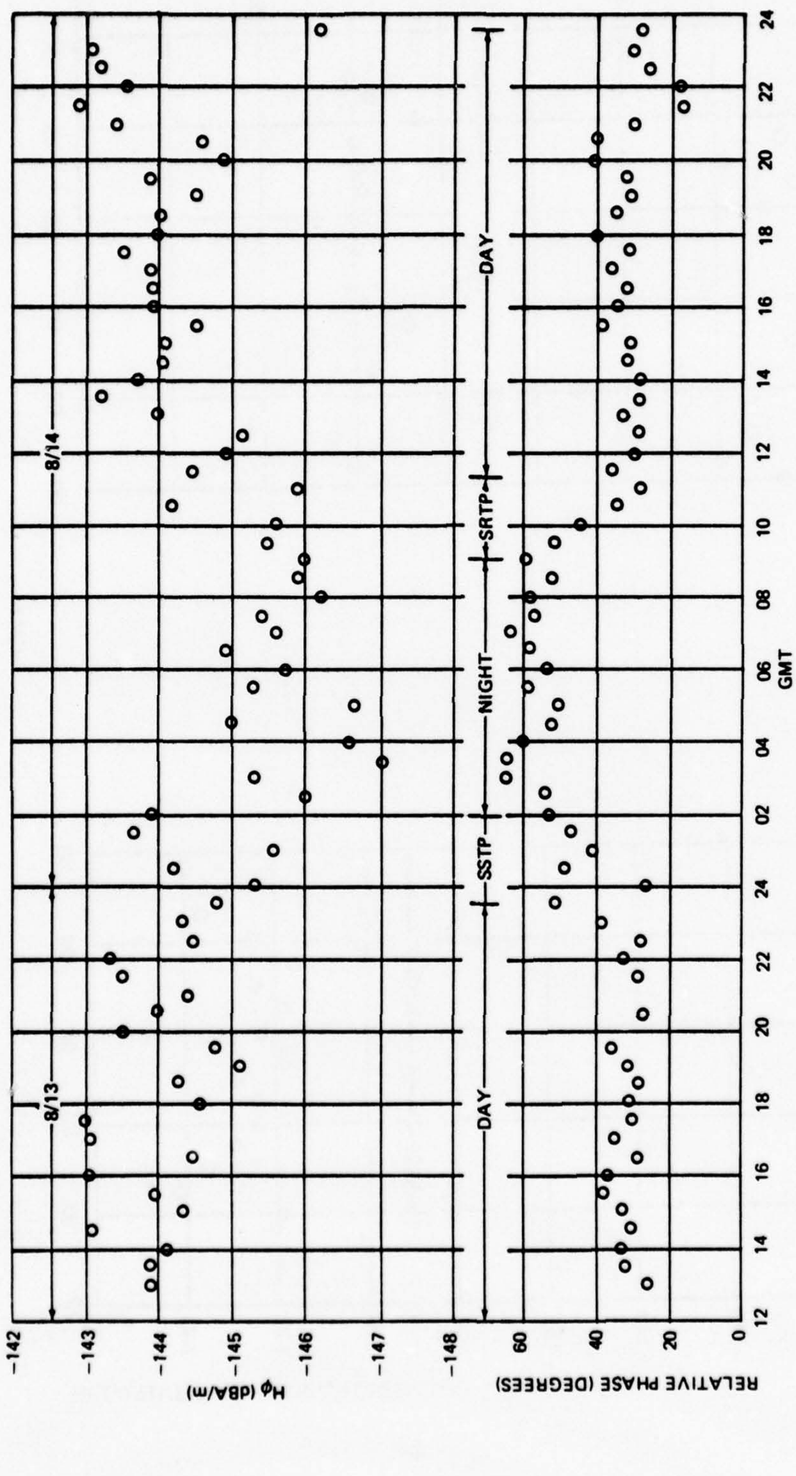


Figure A-3. 13 and 14 August Connecticut Field Strengths Versus GMT (WTF EW antenna only)

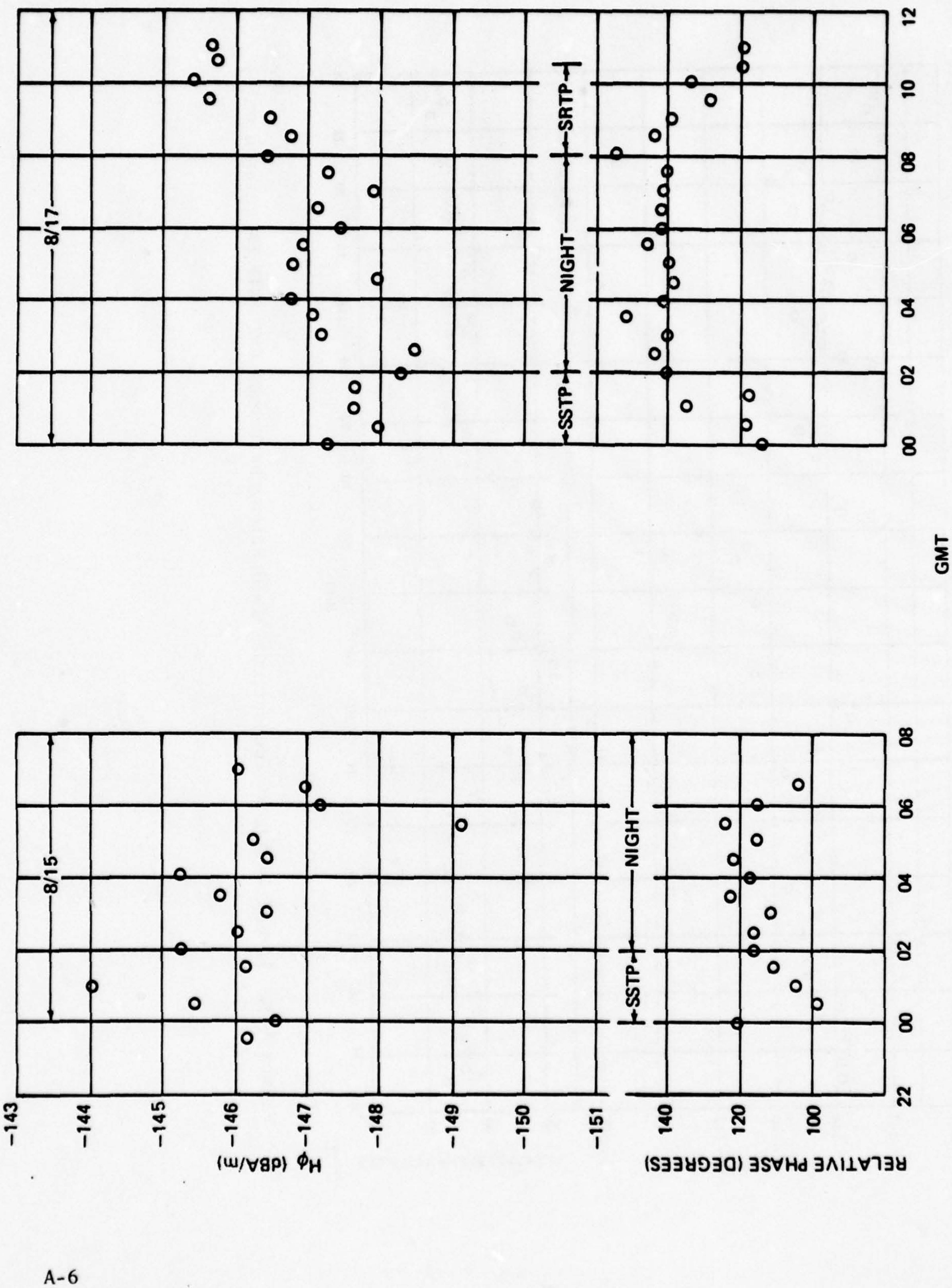


Figure A-4. 15 and 17 August Connecticut Field Strengths Versus GMT (ψ = 117°)

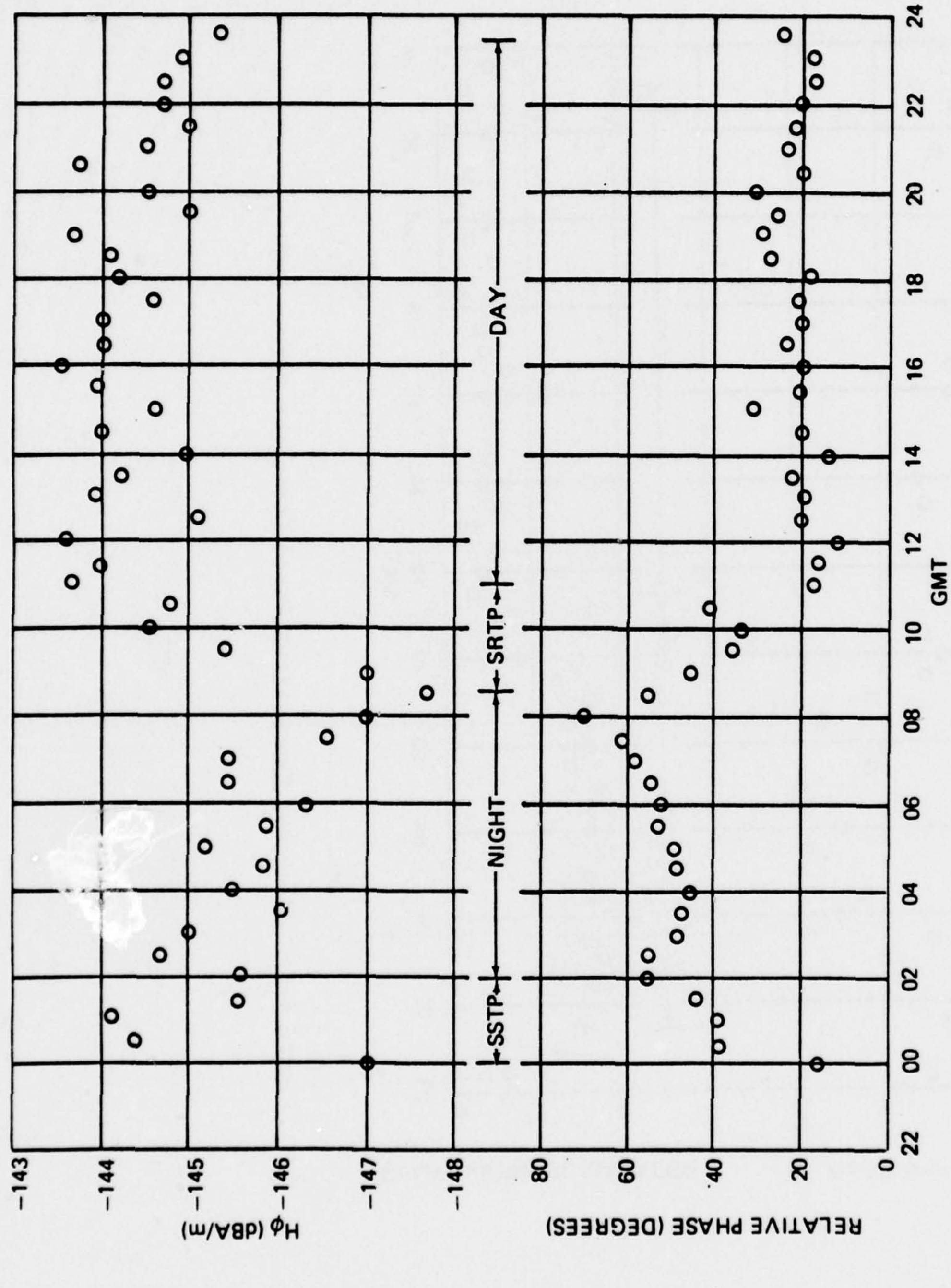


Figure A-5. 18 August Connecticut Field Strengths Versus GMT (ψ = 207°)

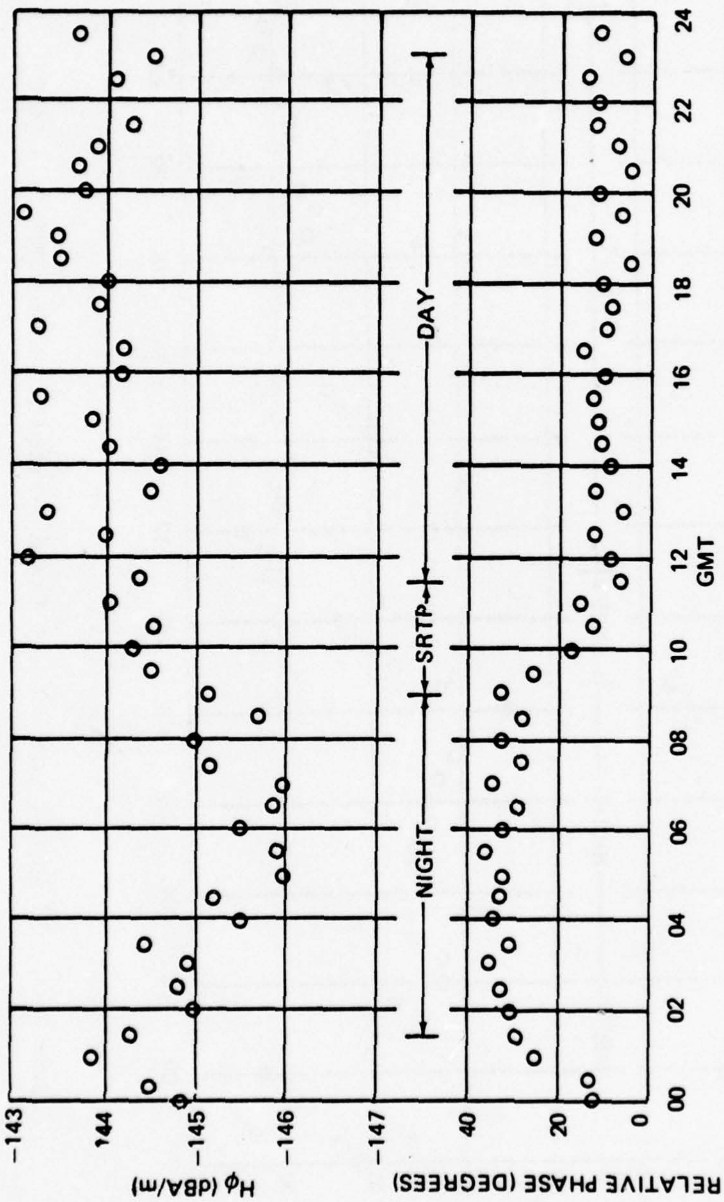


Figure A-6. 22 August Connecticut Field Strengths Versus GMT (ψ = 21°)

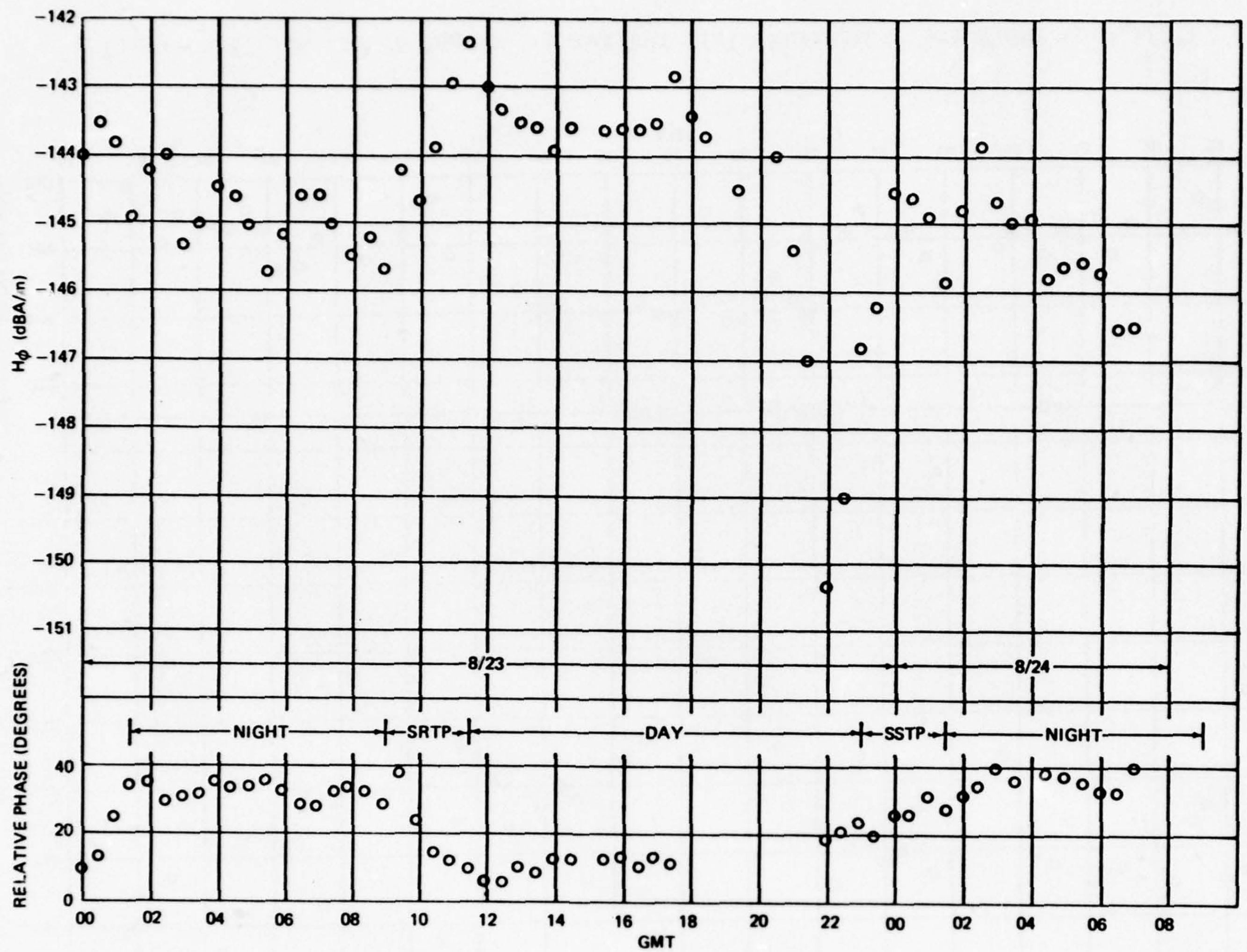


Figure A-7. 23 and 24 August Connecticut Field Strengths Versus GMT (ψ = 21°)

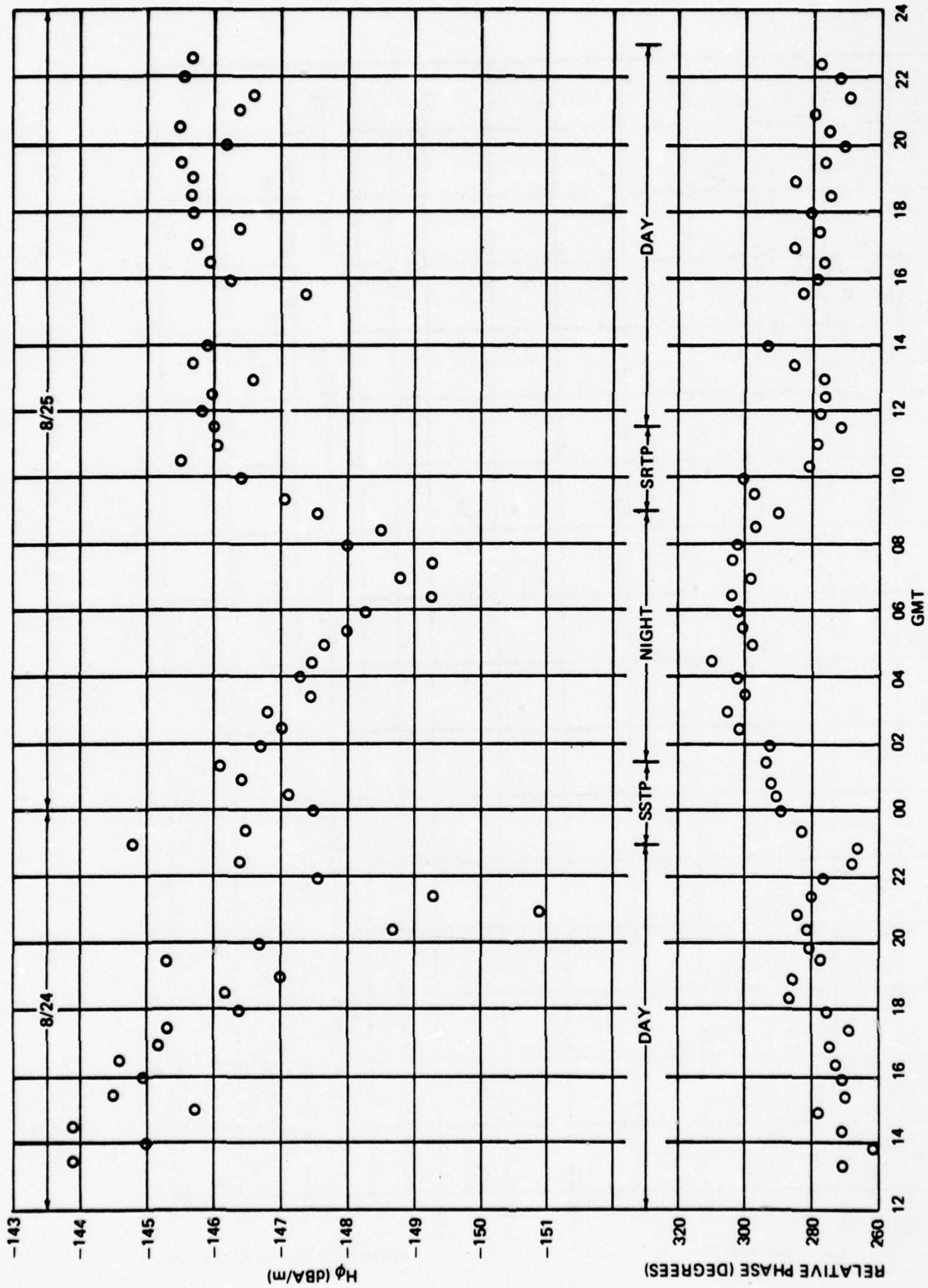


Figure A-8. 24 and 25 August Connecticut Field Strengths Versus GMT (ψ = 110°)

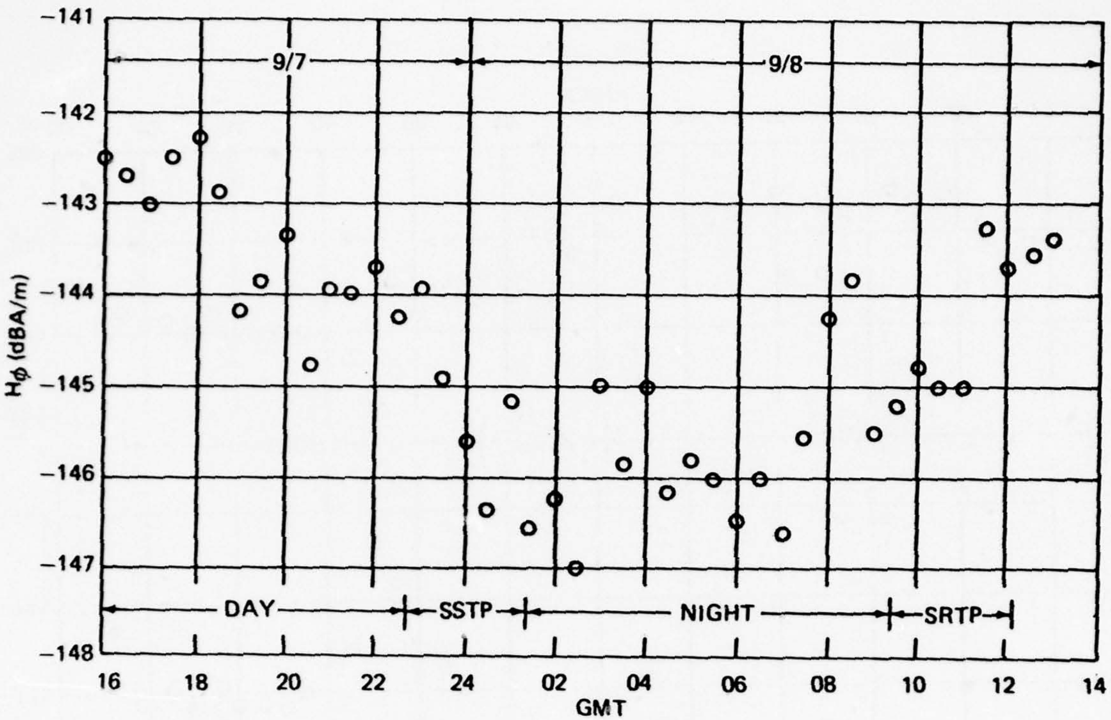


Figure A-9. 7 and 8 September Connecticut Field Strengths Versus GMT (ψ = 21°)

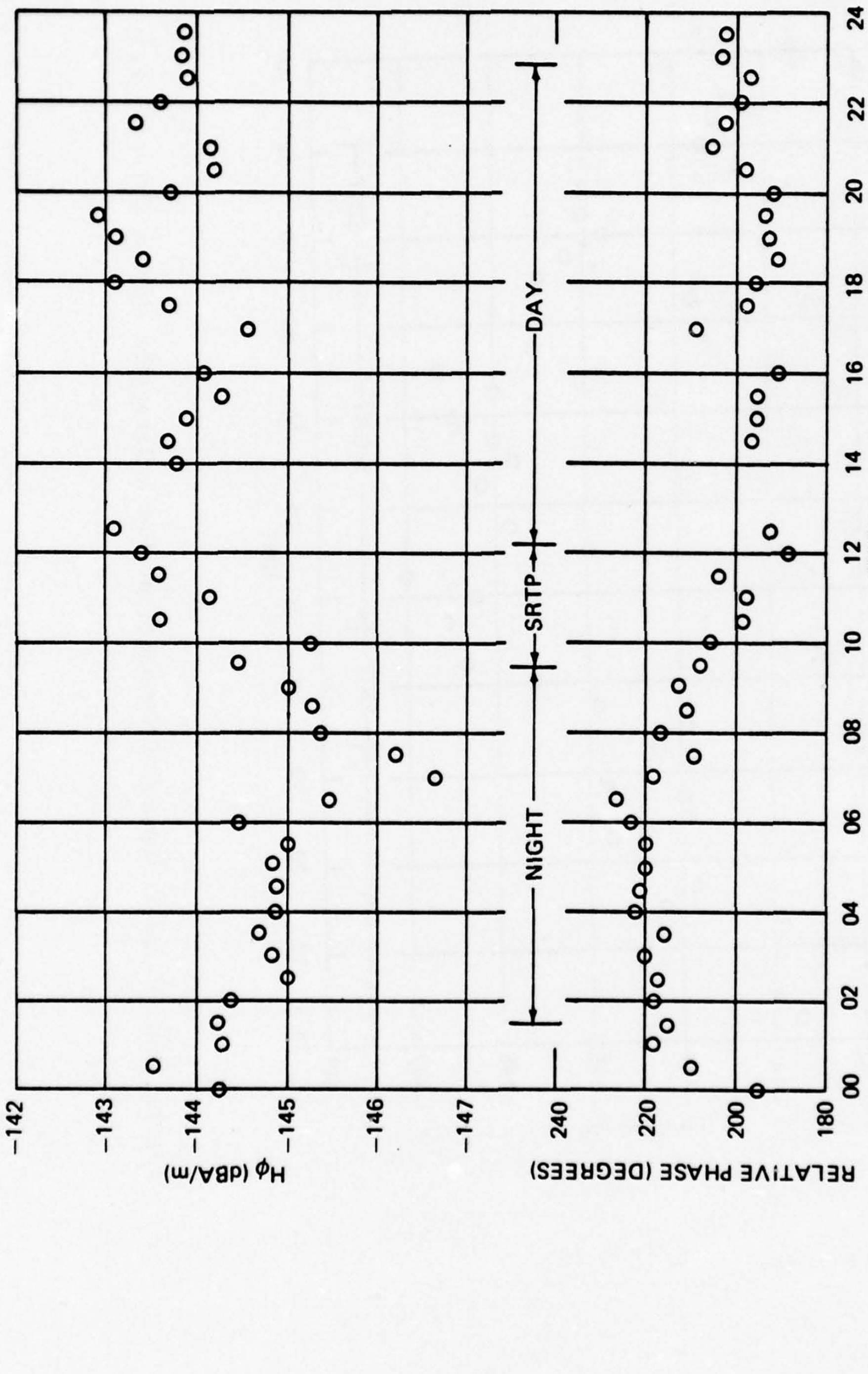


Figure A-10. 10 September Connecticut Field Strengths Versus GMT (ψ = 21°)

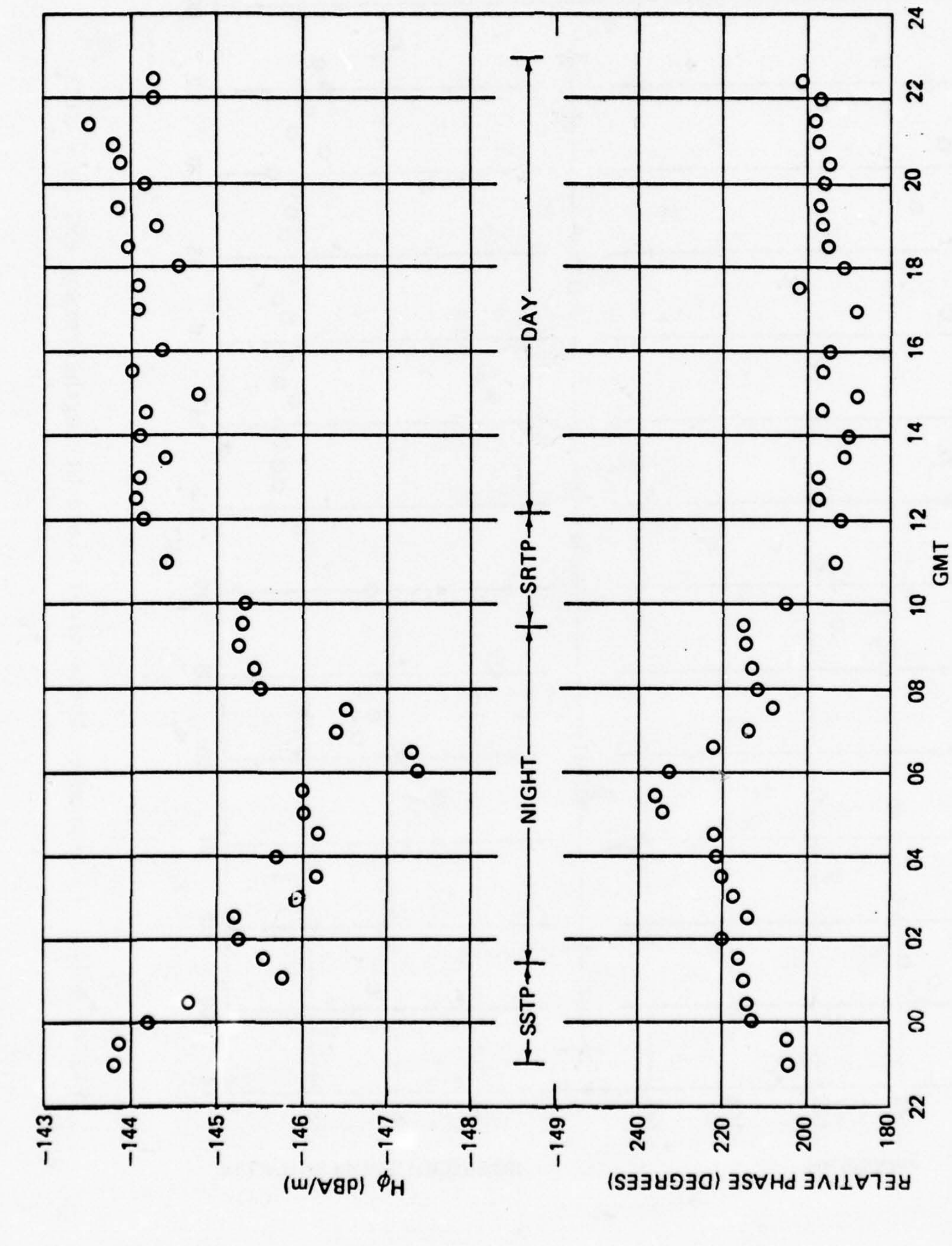


Figure A-11. 11 September Connecticut Field Strengths Versus GMT (ψ = 21°)

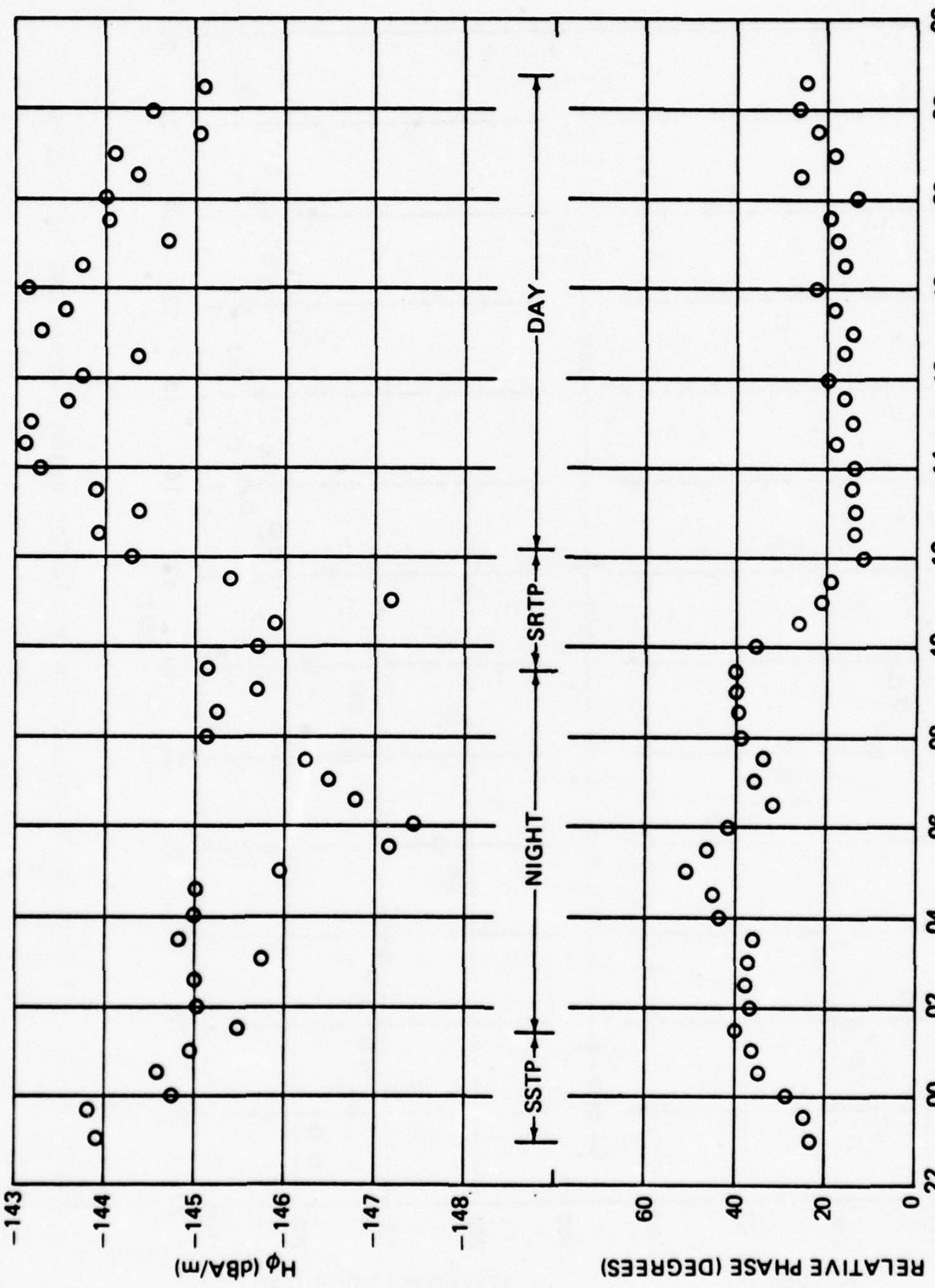


Figure A-12. 12 September Connecticut Field Strengths Versus GMT (ψ = 21°)

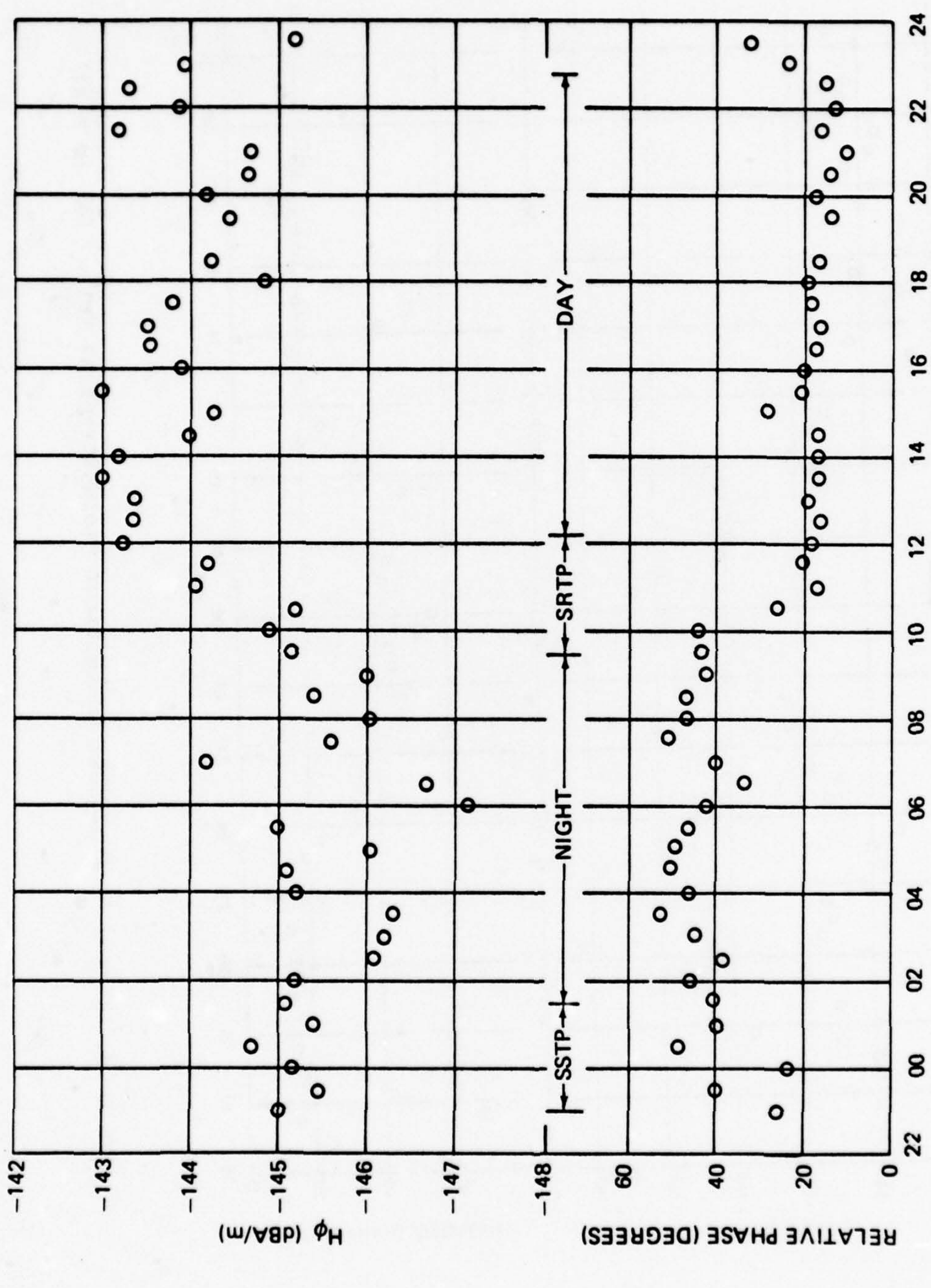


Figure A-13. 13 September Connecticut Field Strengths Versus GMT (ψ = 21°)

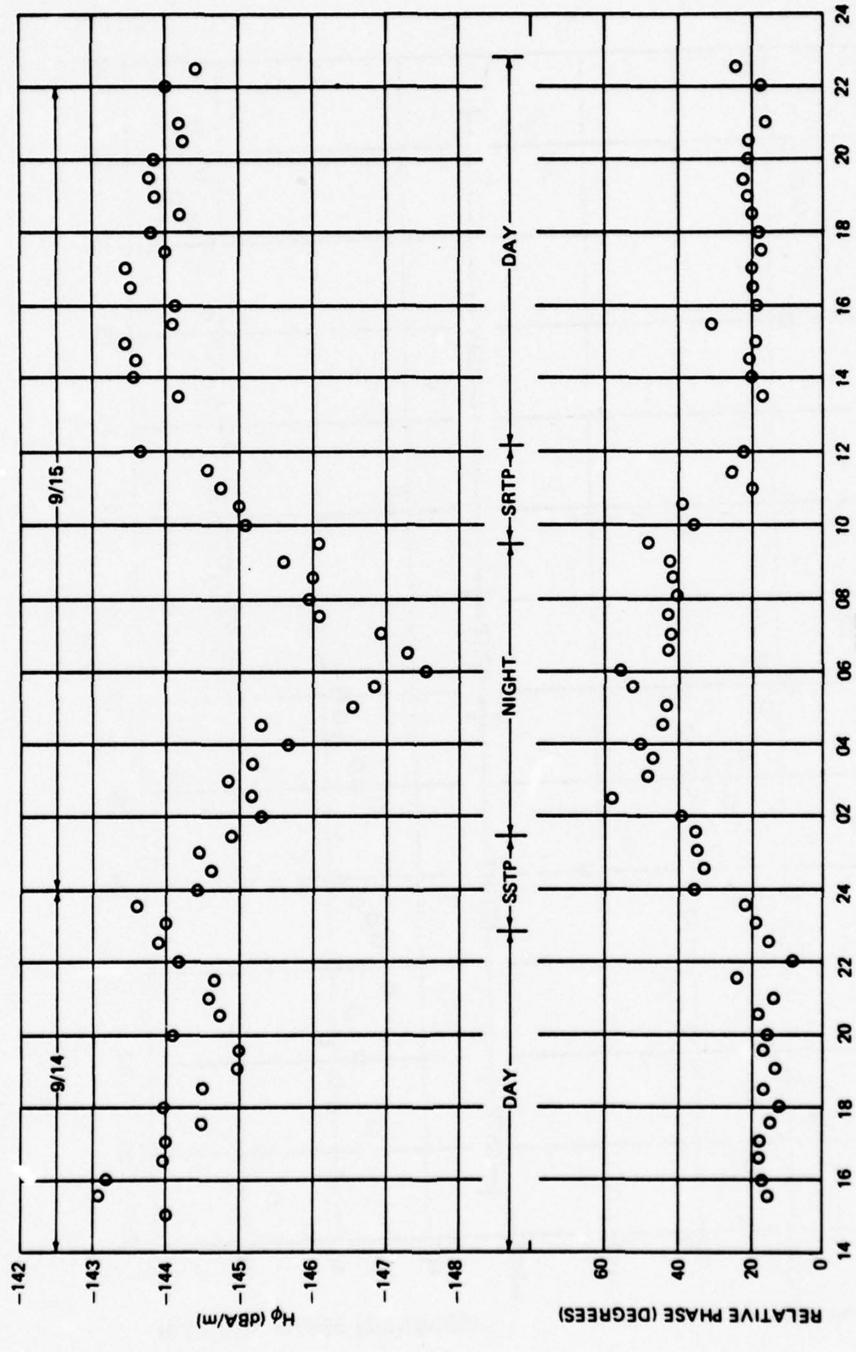


Figure A-14. 14 and 15 September Connecticut Field Strengths Versus GMT (ψ = 21°)

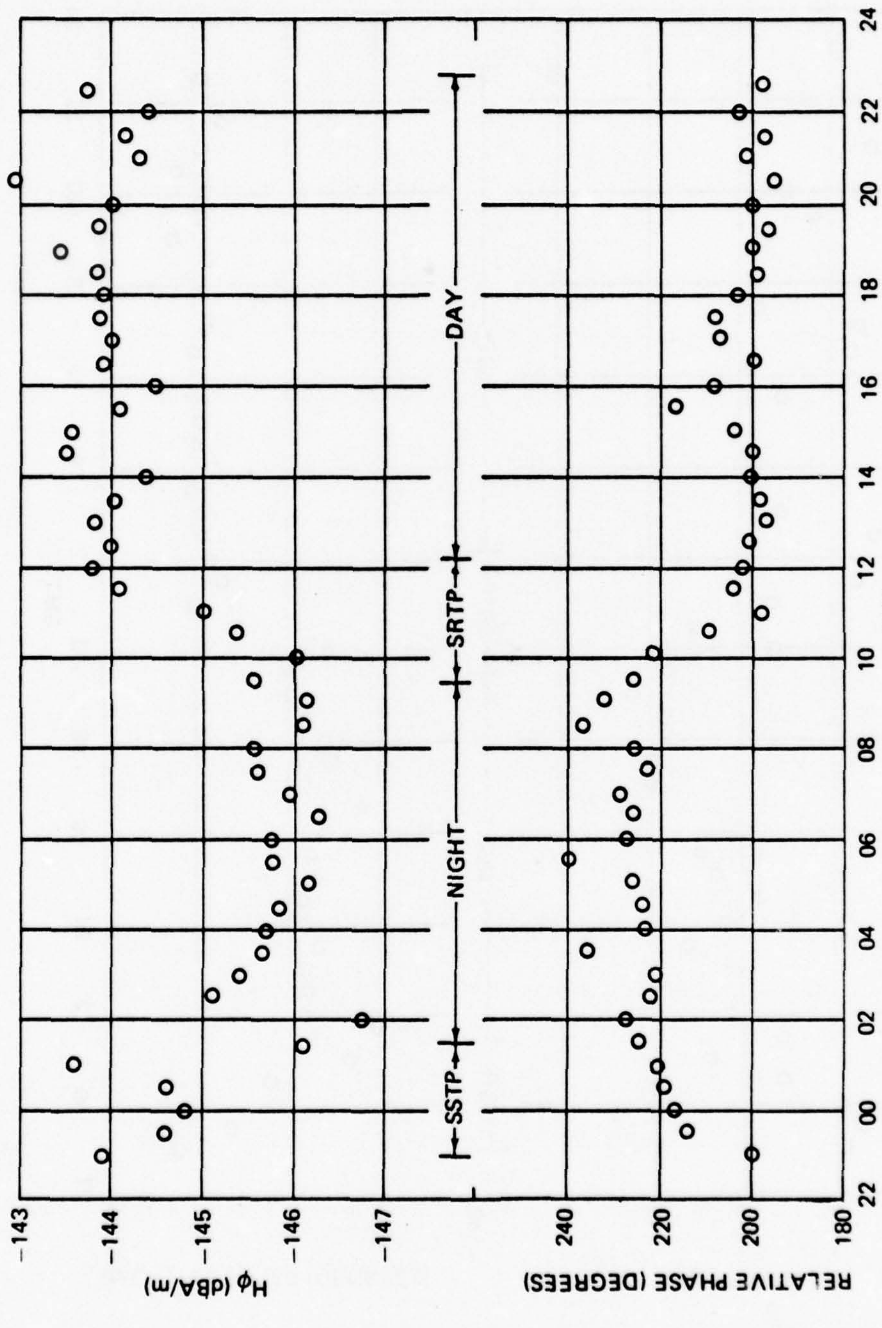


Figure A-15. 10 September Connecticut Field Strengths Versus GMT (ψ = 21°)

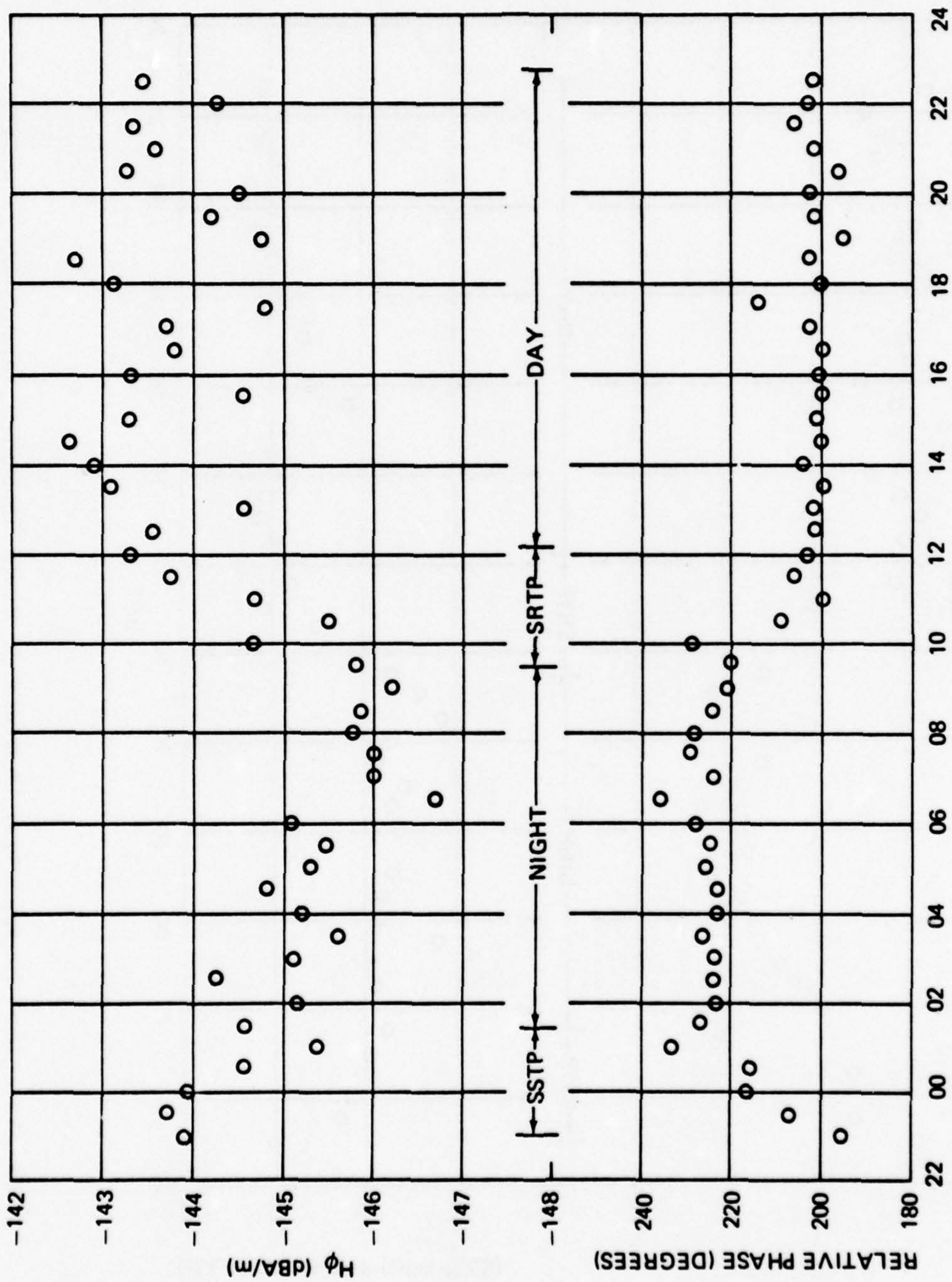


Figure A-16. 17 September Connecticut Field Strengths Versus GMT (ψ = 21°)

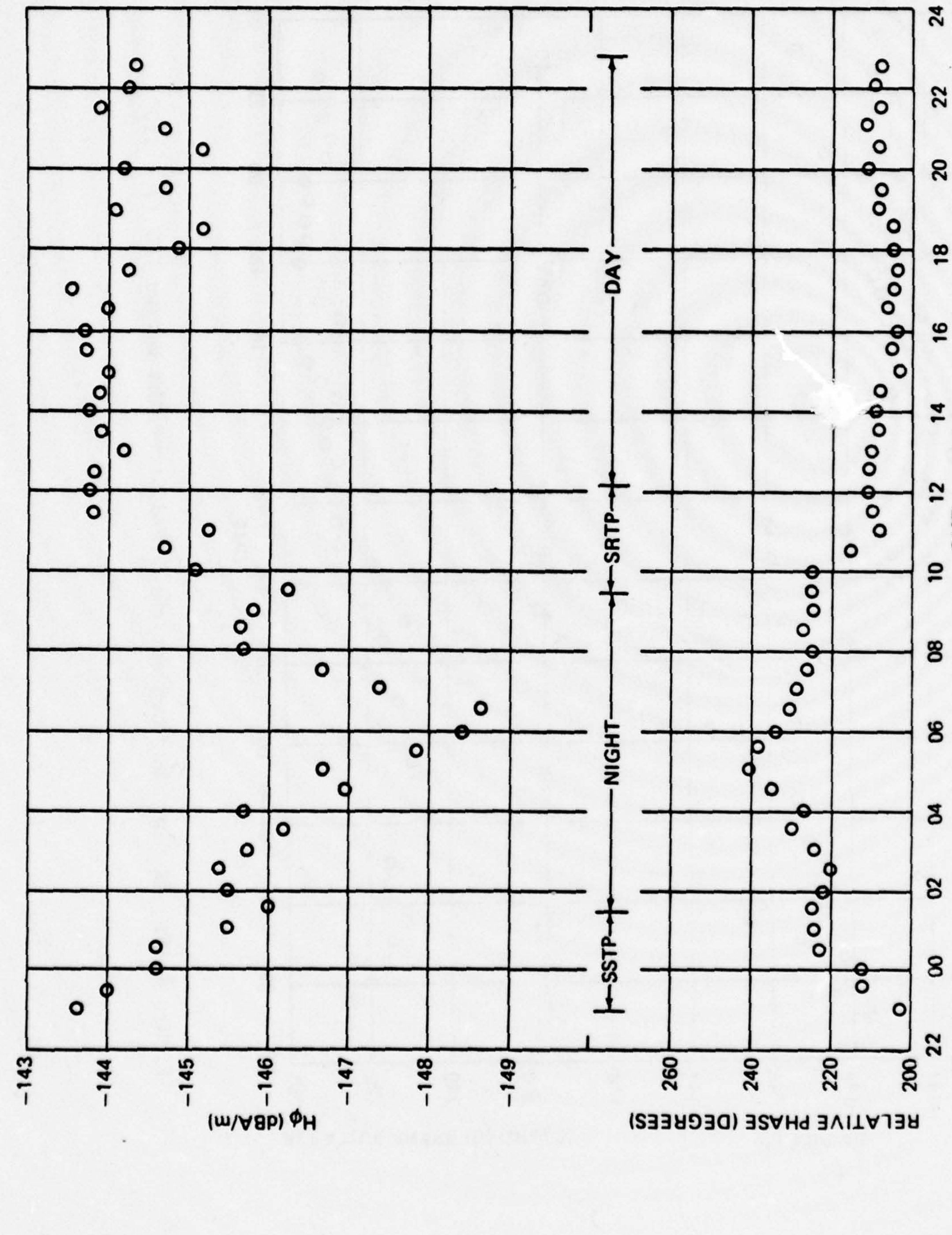


Figure A-17. 18 September Connecticut Field Strengths Versus GMT (ψ = 21°)

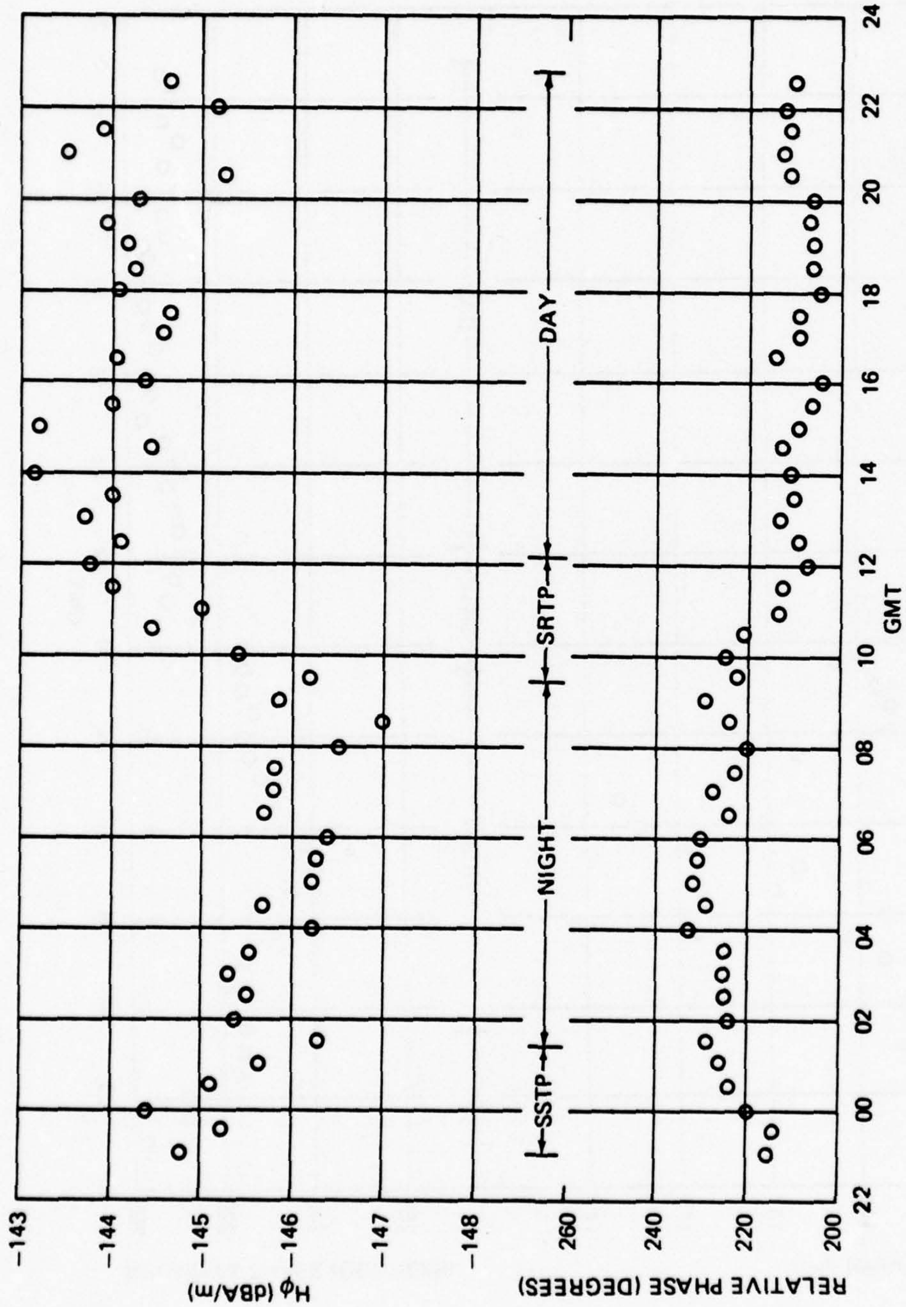


Figure A-18. 19 September Connecticut Field Strengths Versus GMT (ψ = 110°)

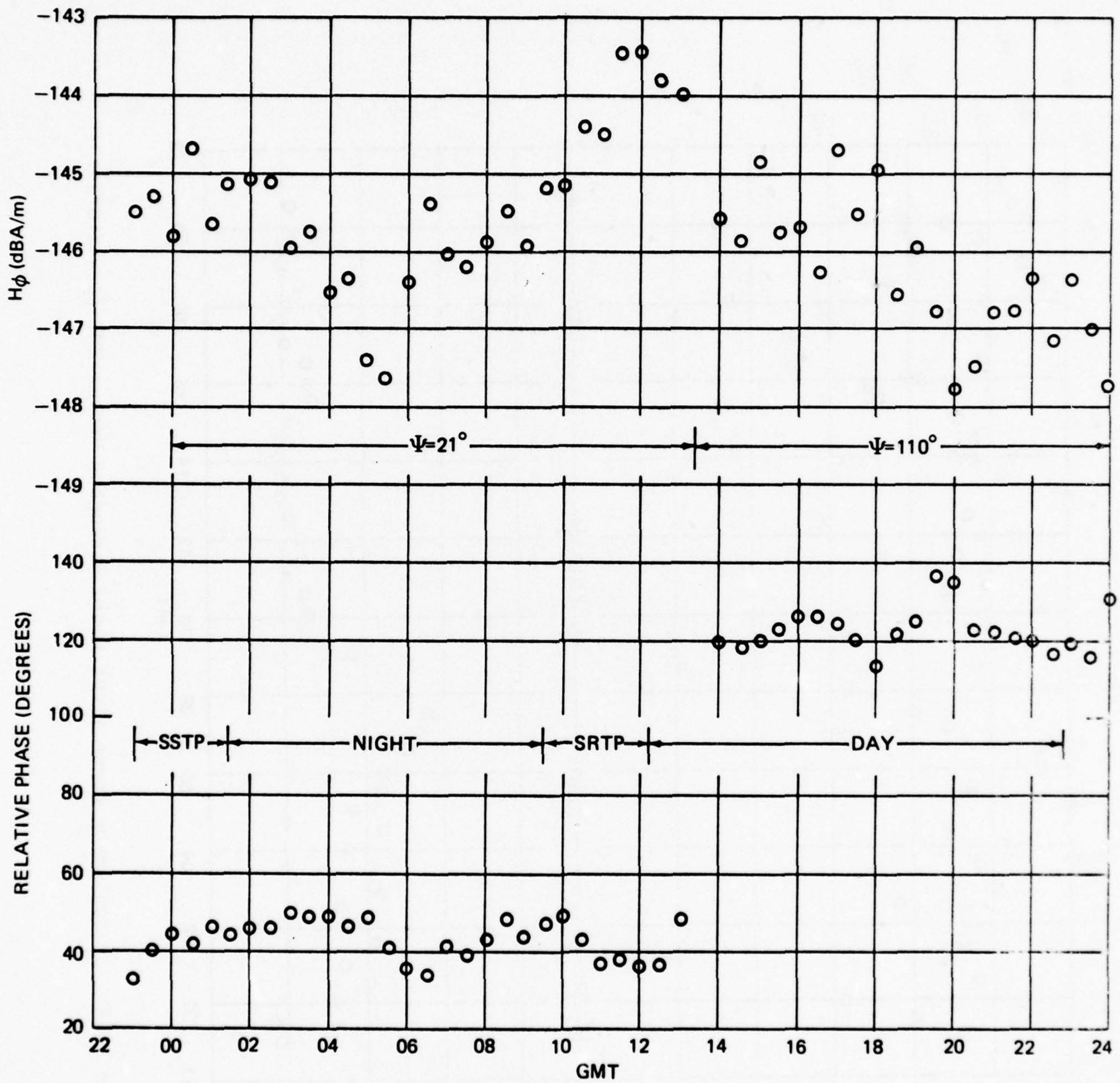


Figure A-19. 20 September Connecticut field Strengths Versus GMT (ψ = 110°)

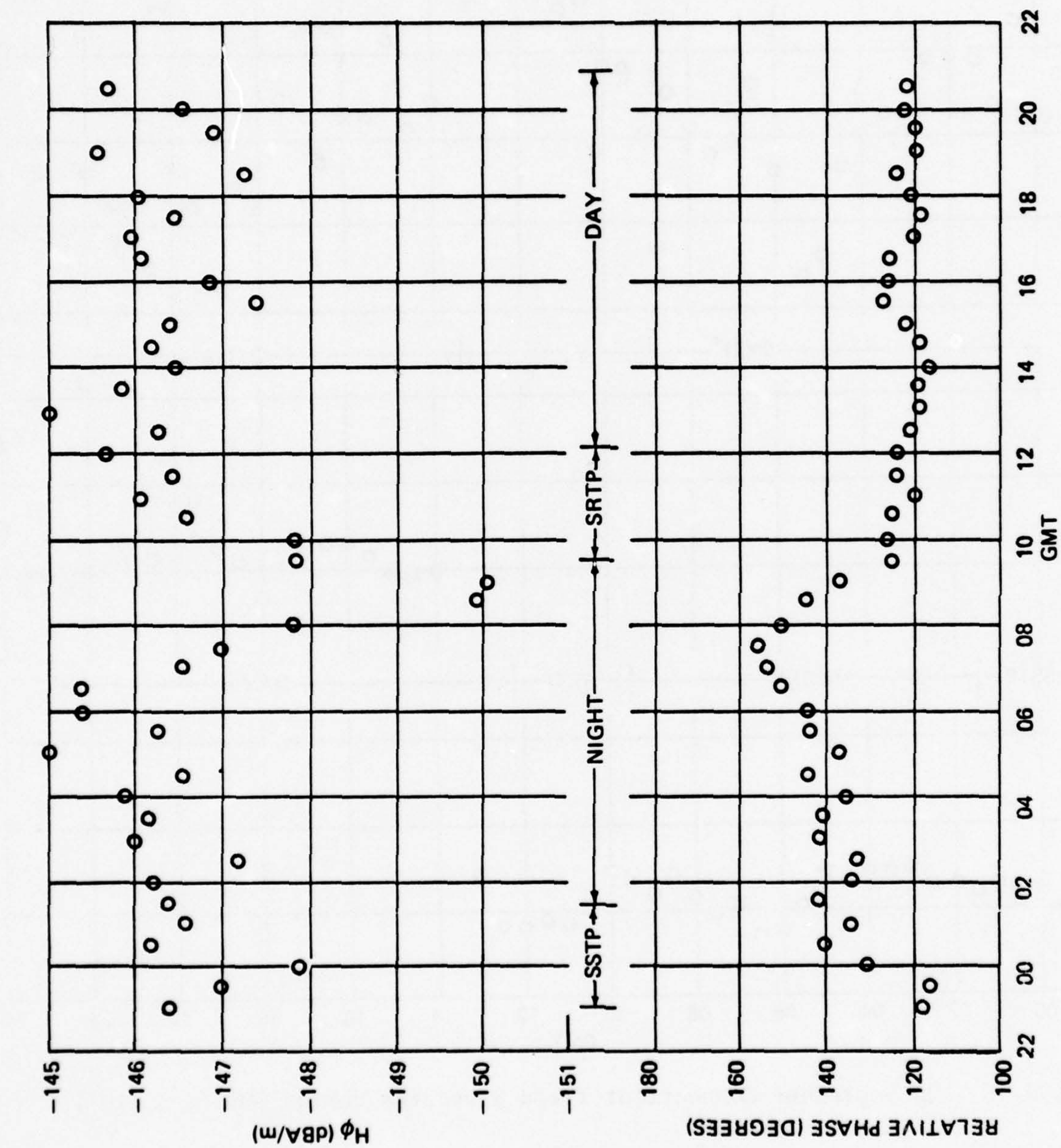


Figure A-20. 21 September Connecticut Field Strengths Versus GMT (ψ = 110°)

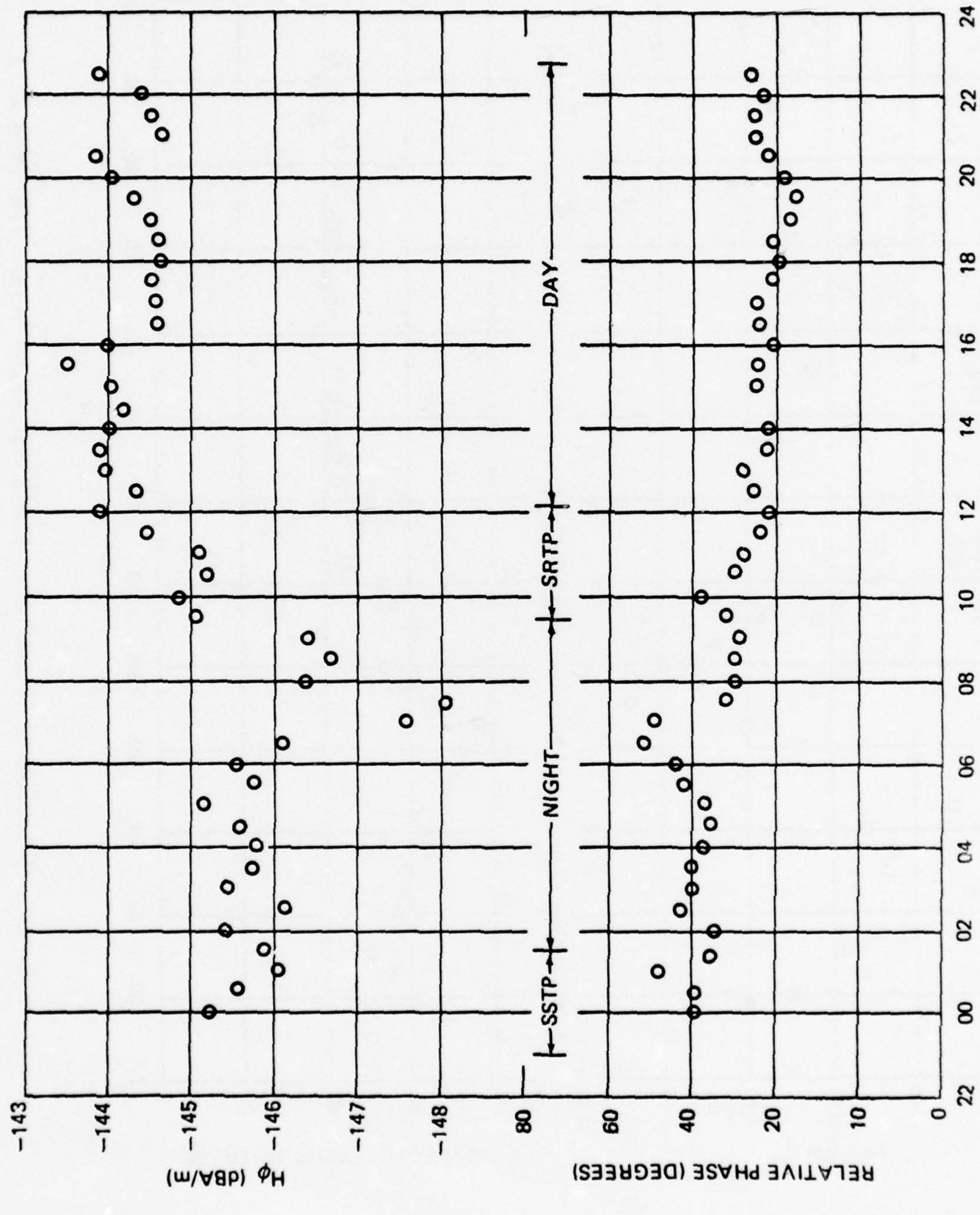


Figure A-21. 22 September Connecticut Field Strengths Versus GMT (ψ = 21°)

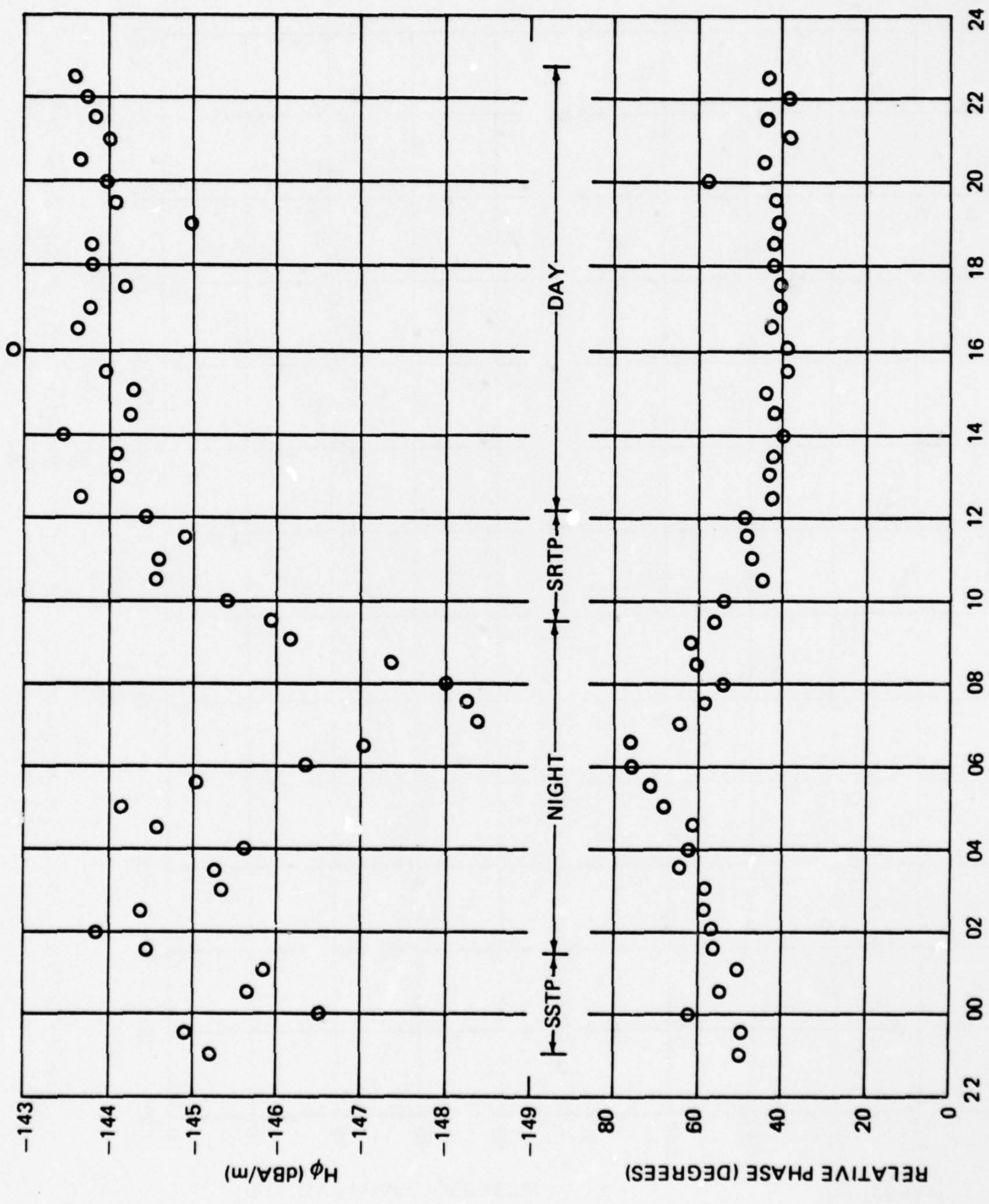


Figure A-22. 23 September Connecticut Field Strengths Versus GMT (ψ = 21°)

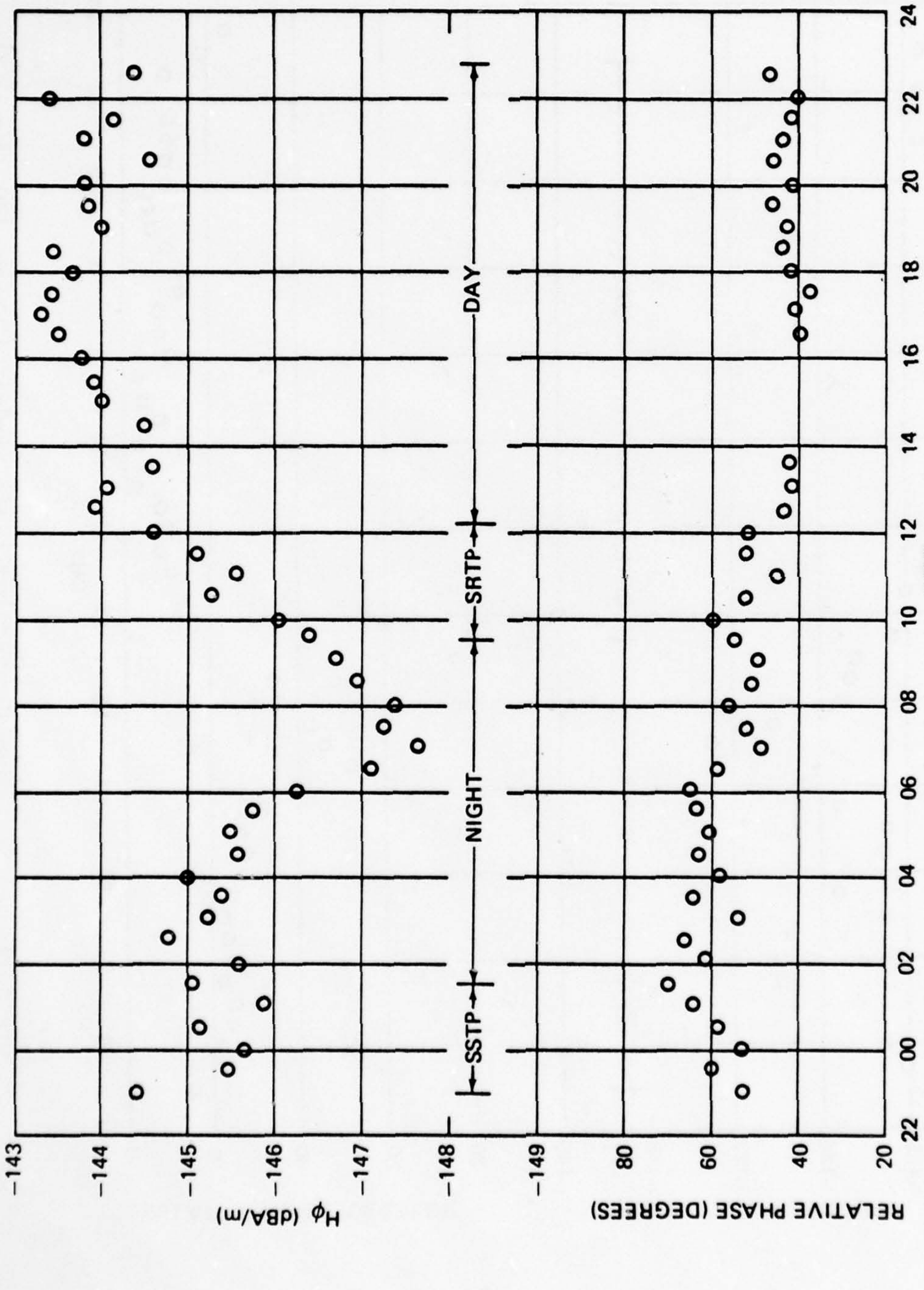


Figure A-23. 24 September Connecticut Field Strengths Versus GMT (ψ = 21°)

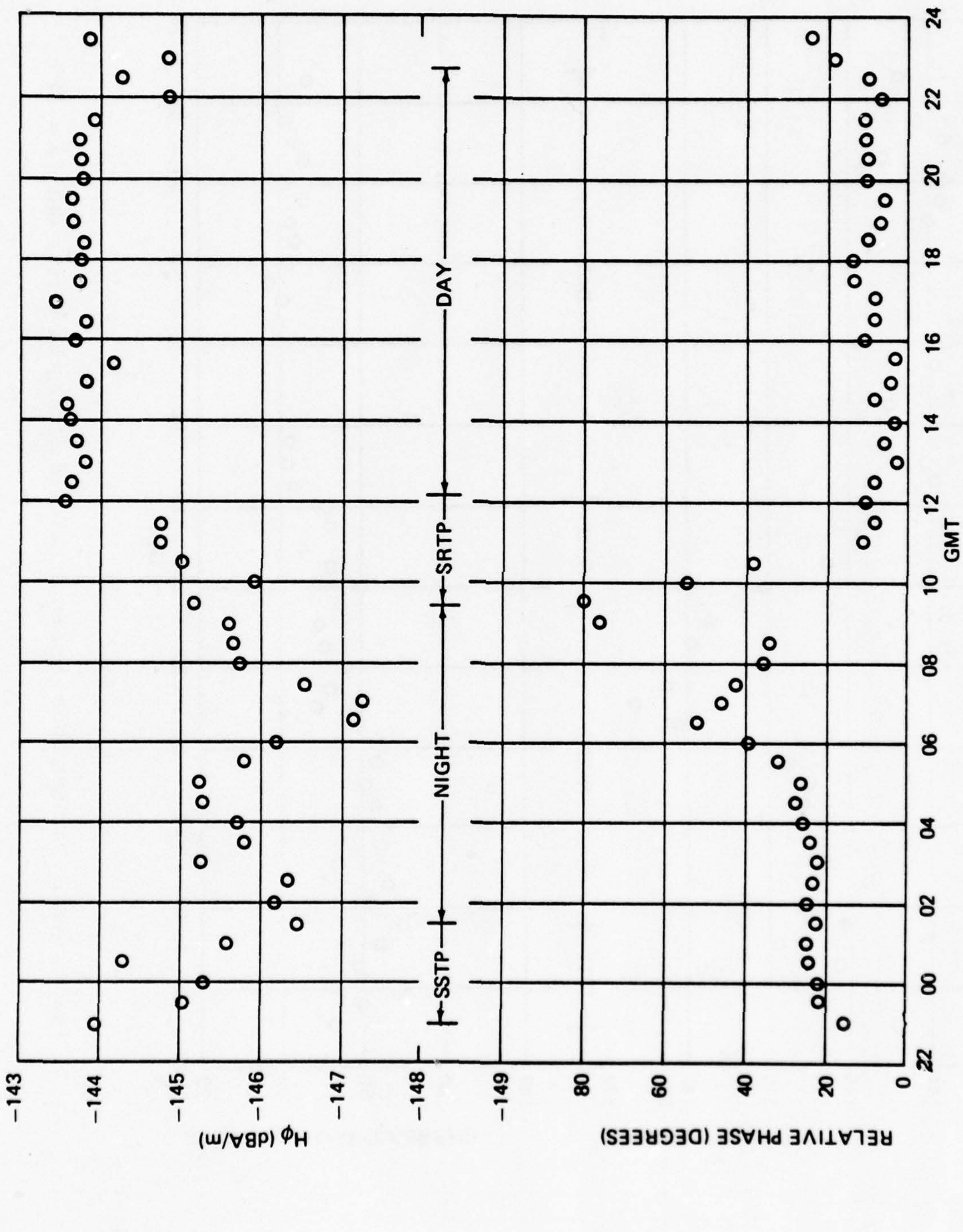


Figure A-24. 25 September Connecticut Field Strengths Versus GMT (ψ = 21°)

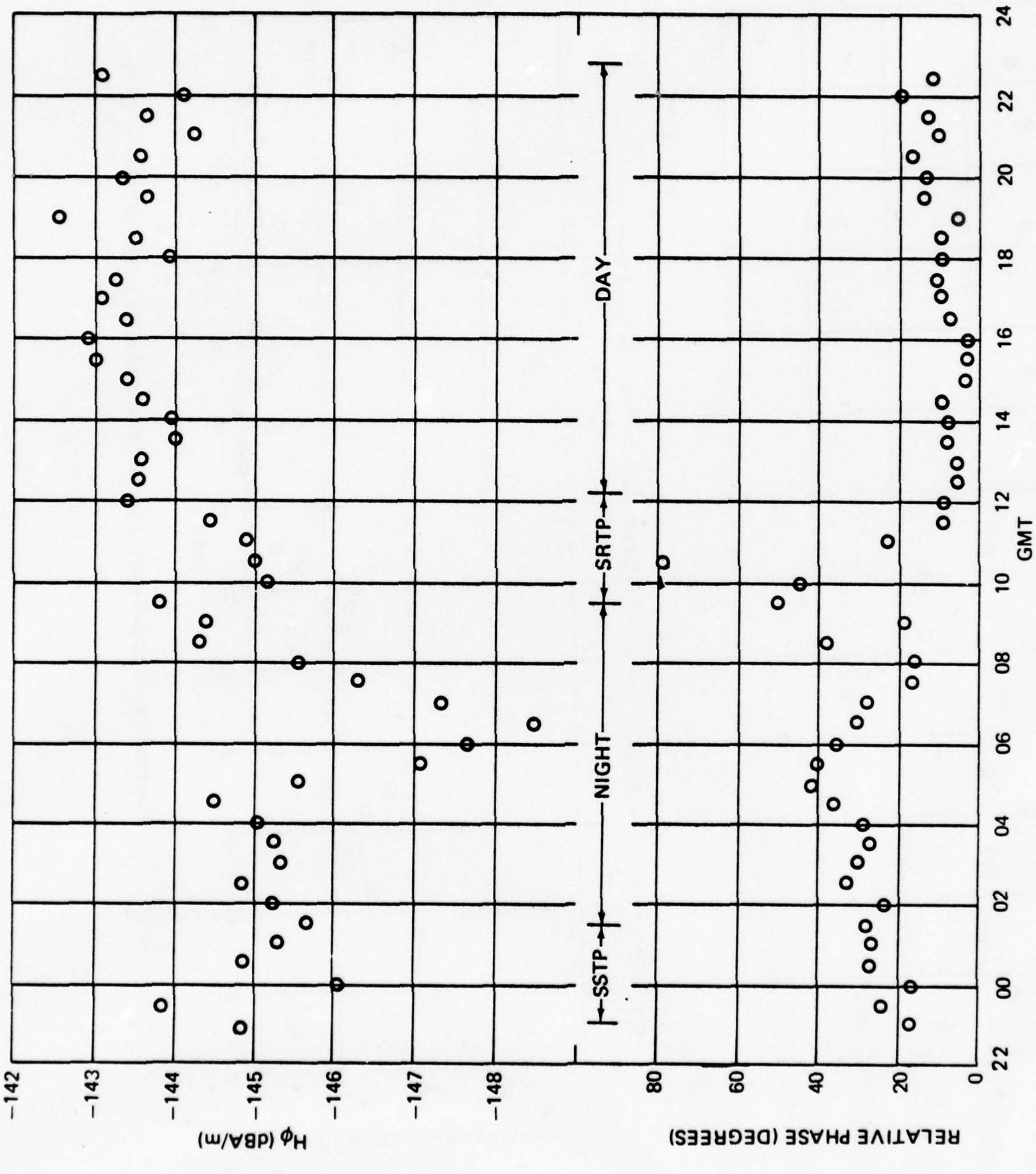


Figure A-25. 26 September Connecticut Field Strengths Versus GMT (ψ = 21°)

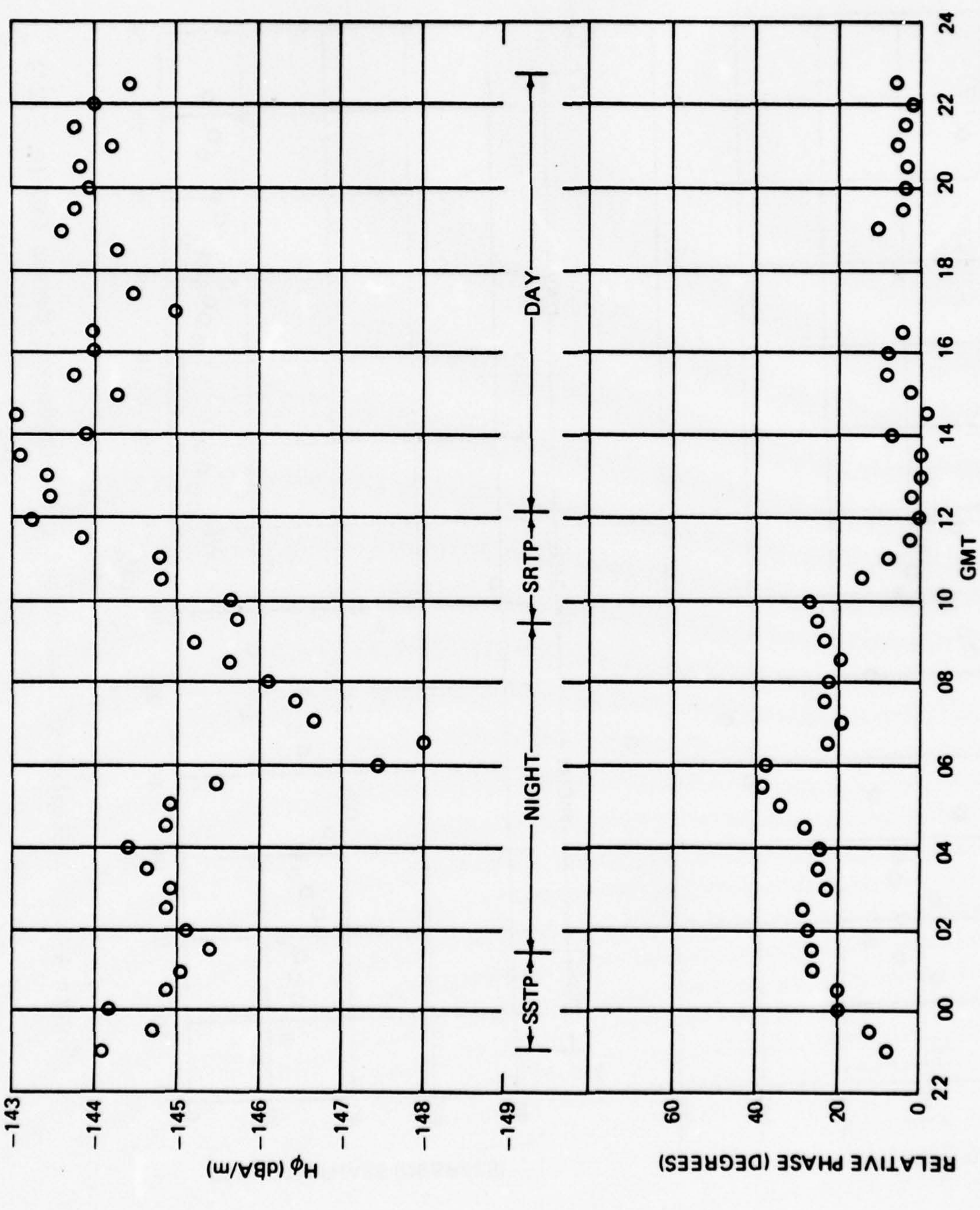


Figure A-26. 28 September Connecticut Field Strengths Versus GMT (ψ = 21°)

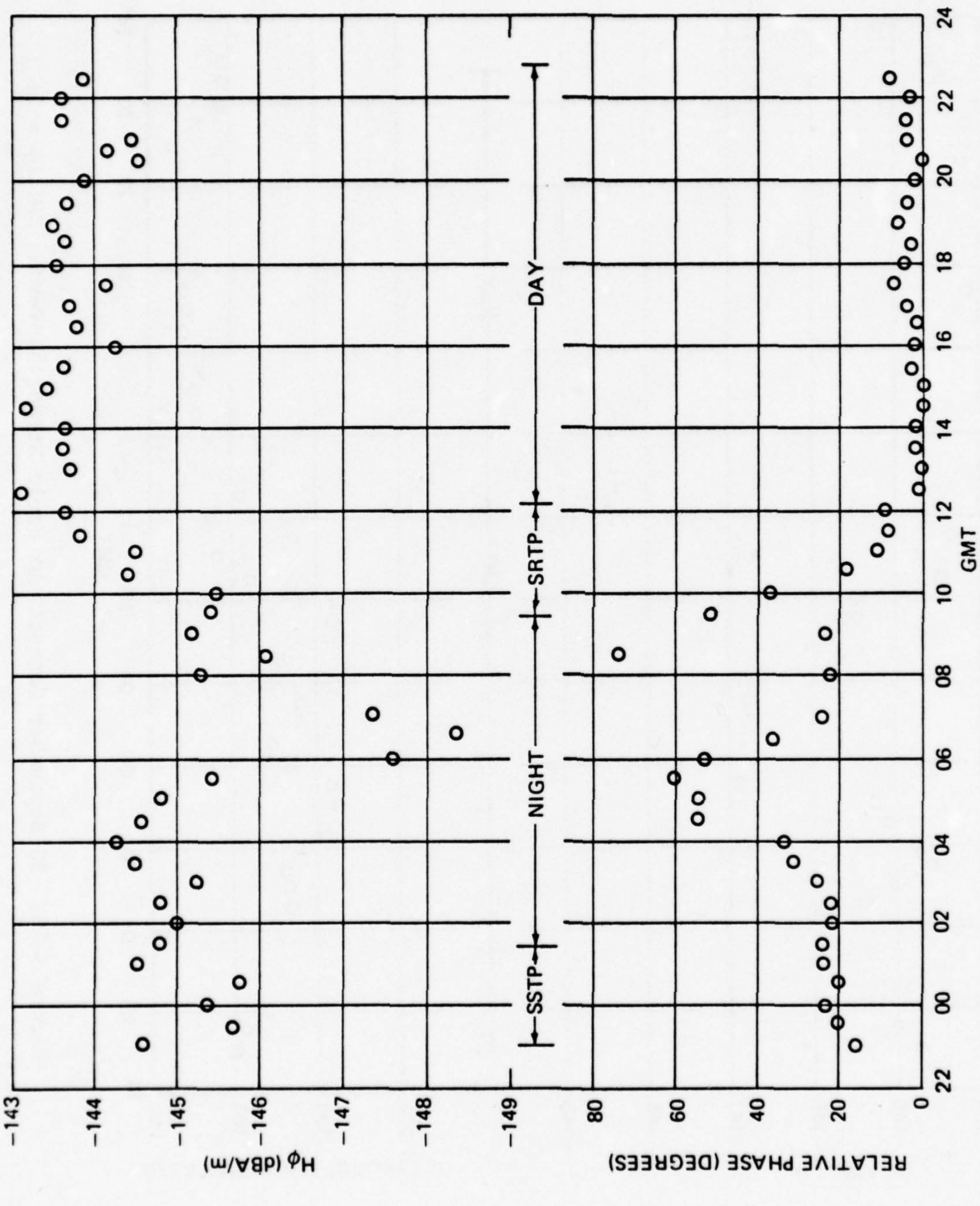


Figure A-27. 29 September Connecticut Field Strengths Versus GMT (ψ = 21°)

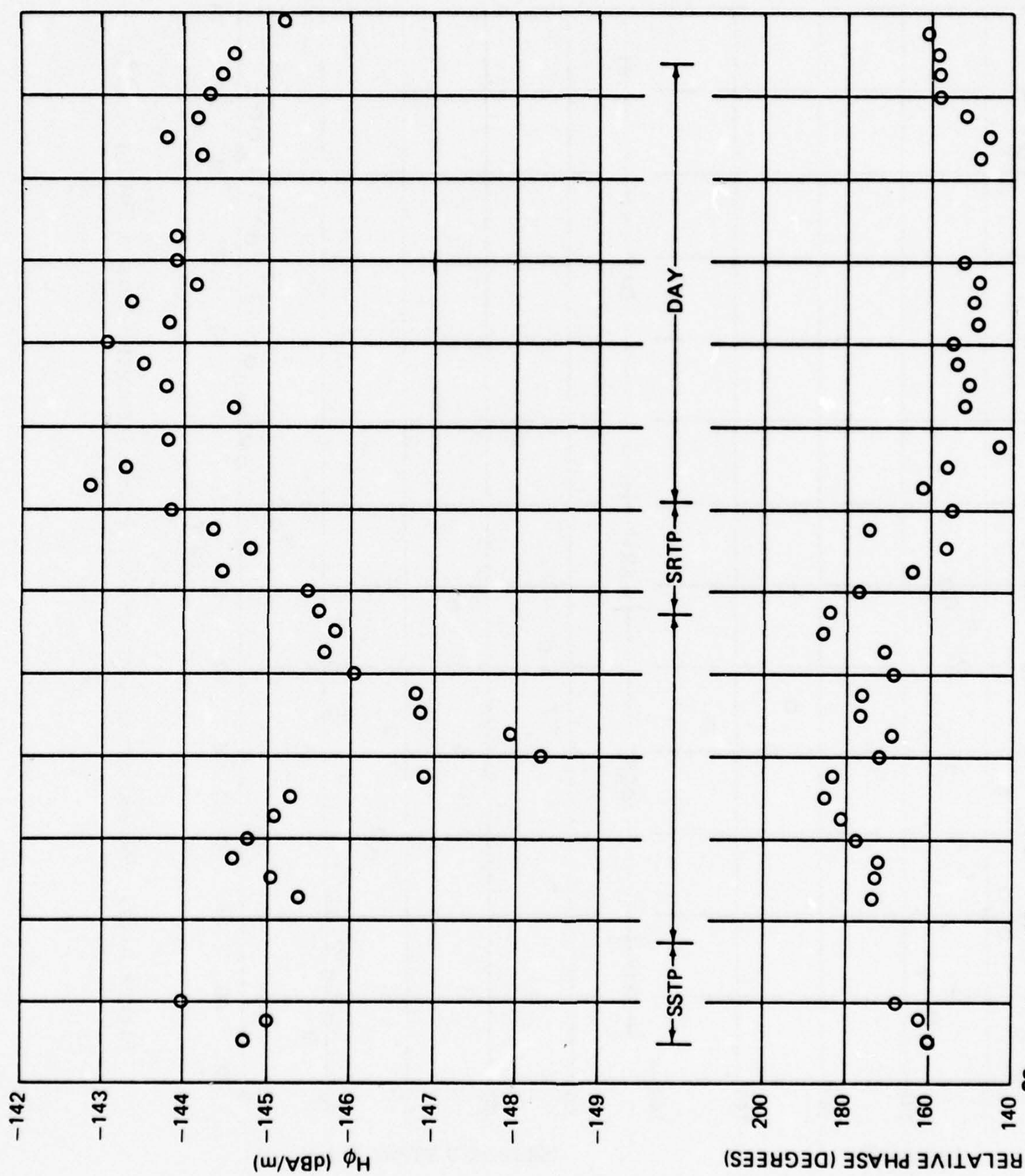


Figure A-28. 30 September Connecticut Field Strengths Versus GMT (ψ = 21°)

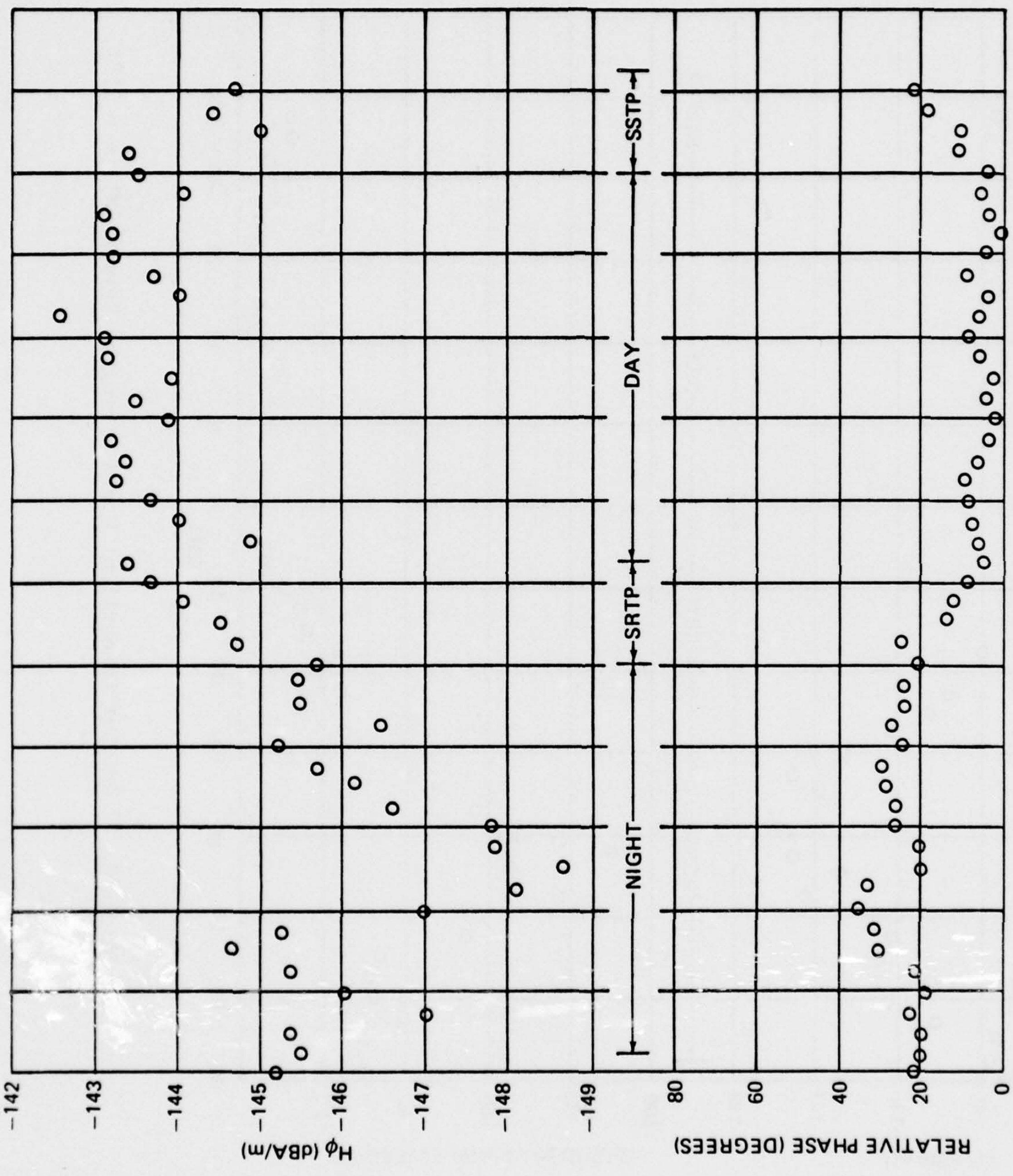


Figure A-29. 1 October Connecticut Field Strengths Versus GMT (ψ = 21°)

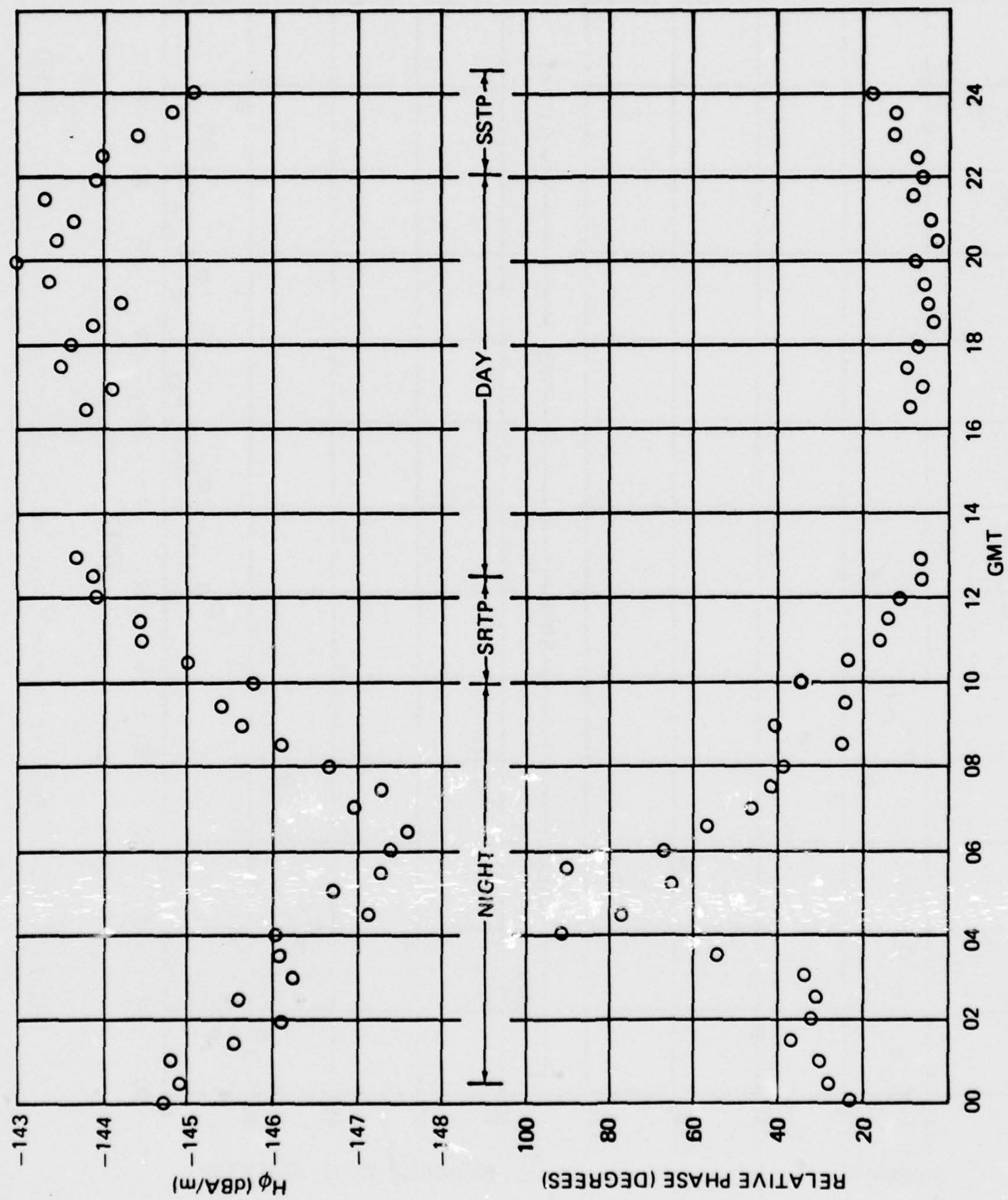


Figure A-30. 2 October Connecticut Field Strengths Versus GMT (ψ = 21°)

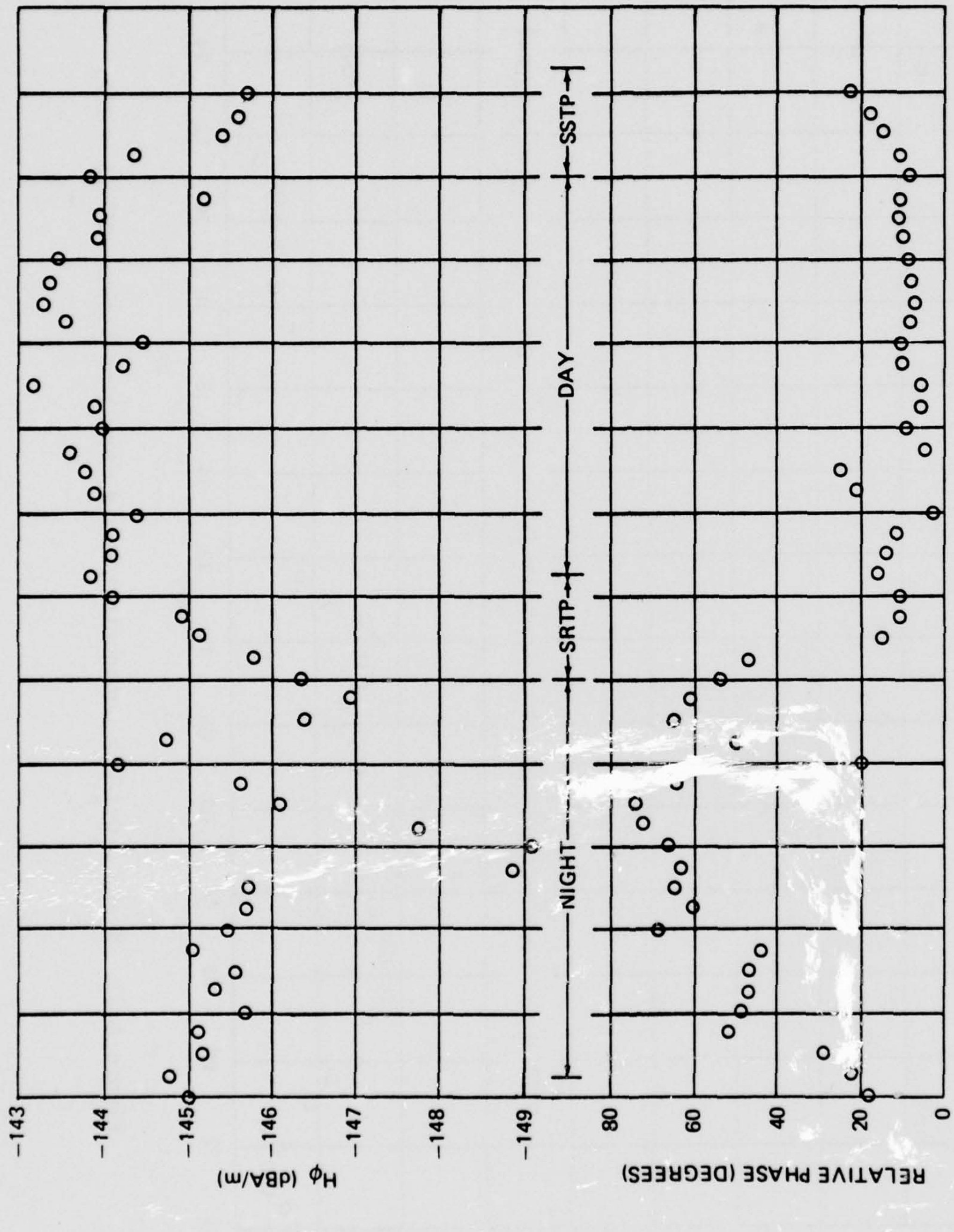


Figure A-31. 3 October Connecticut Field Strengths Versus GMT (ψ = 21°)

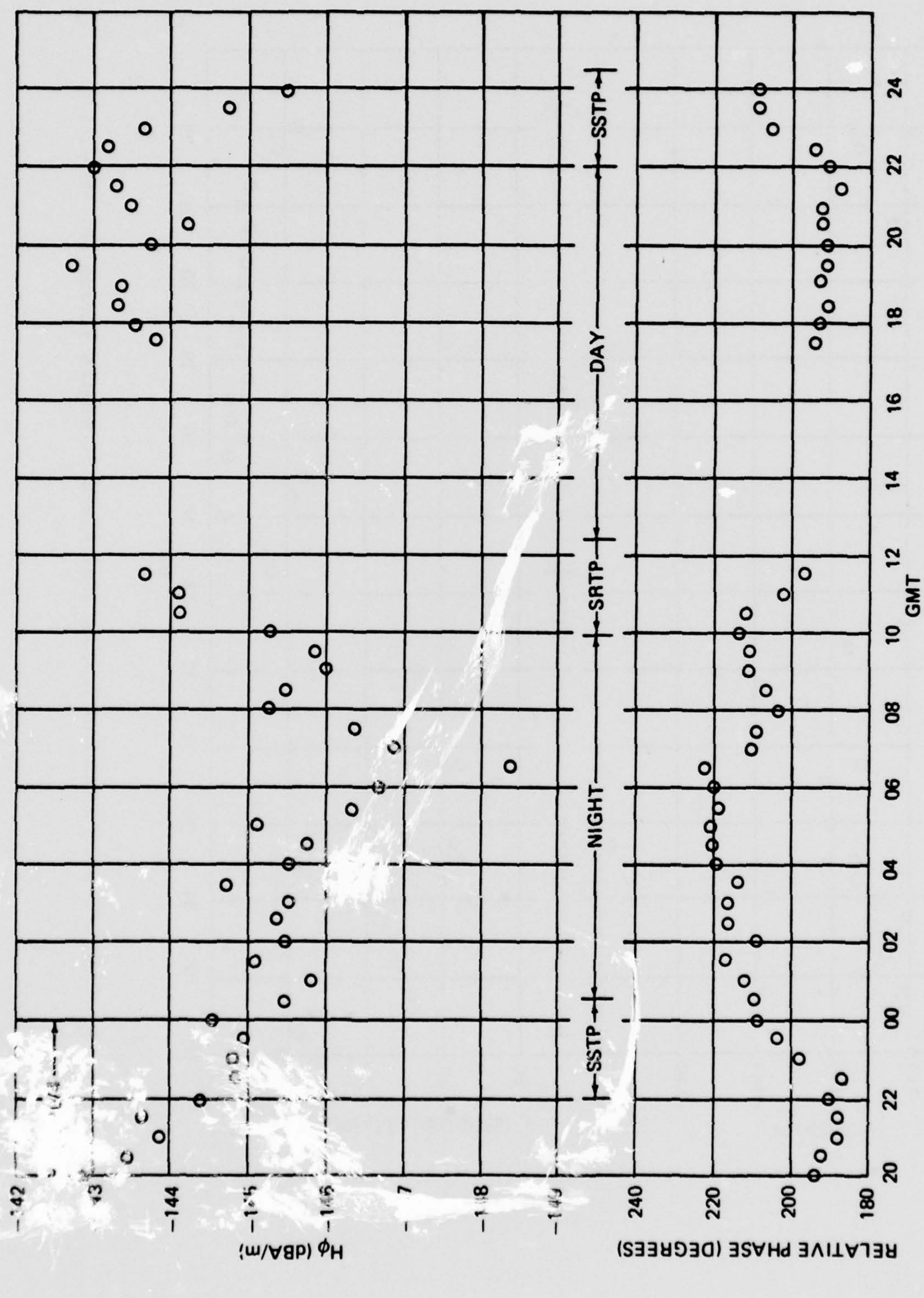


Figure A-32. 4 and 5 October Connecticut Field Strengths Versus GMT (ψ = 21°)

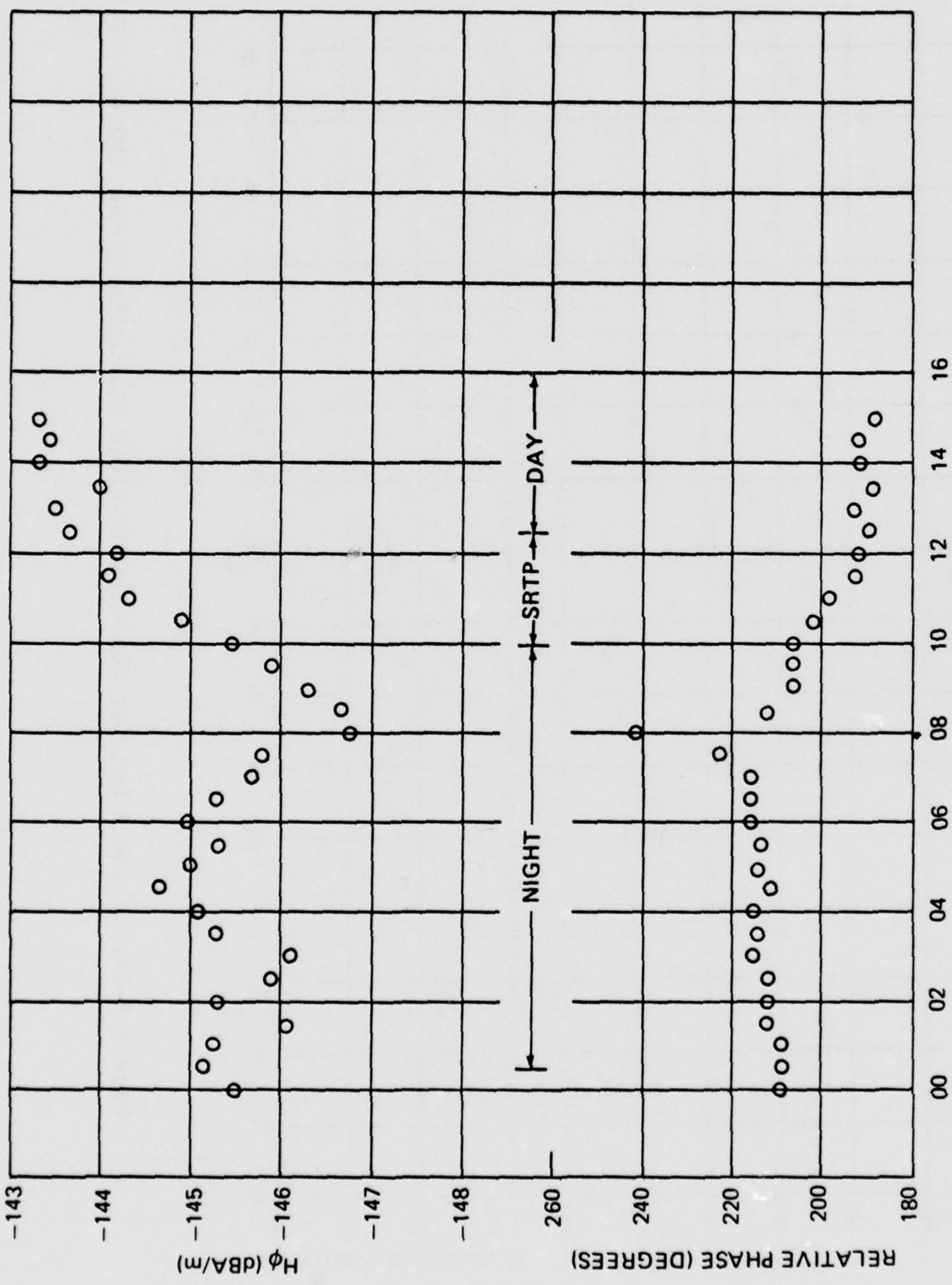


Figure A-33. 6 October Connecticut Field Strengths Versus GMT (ψ = 21°)

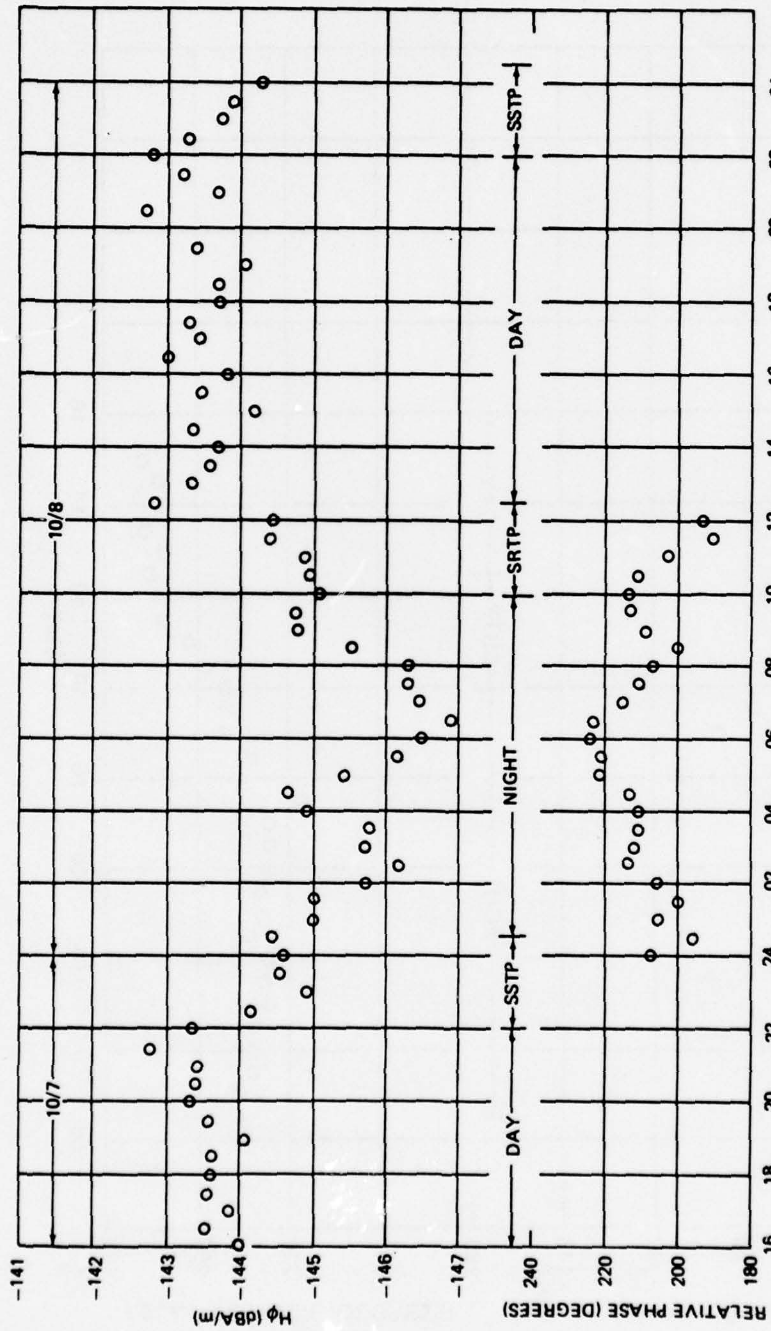


Figure A-34. 7 and 8 October Connecticut Field Strengths Versus GMT (ψ = 21°)

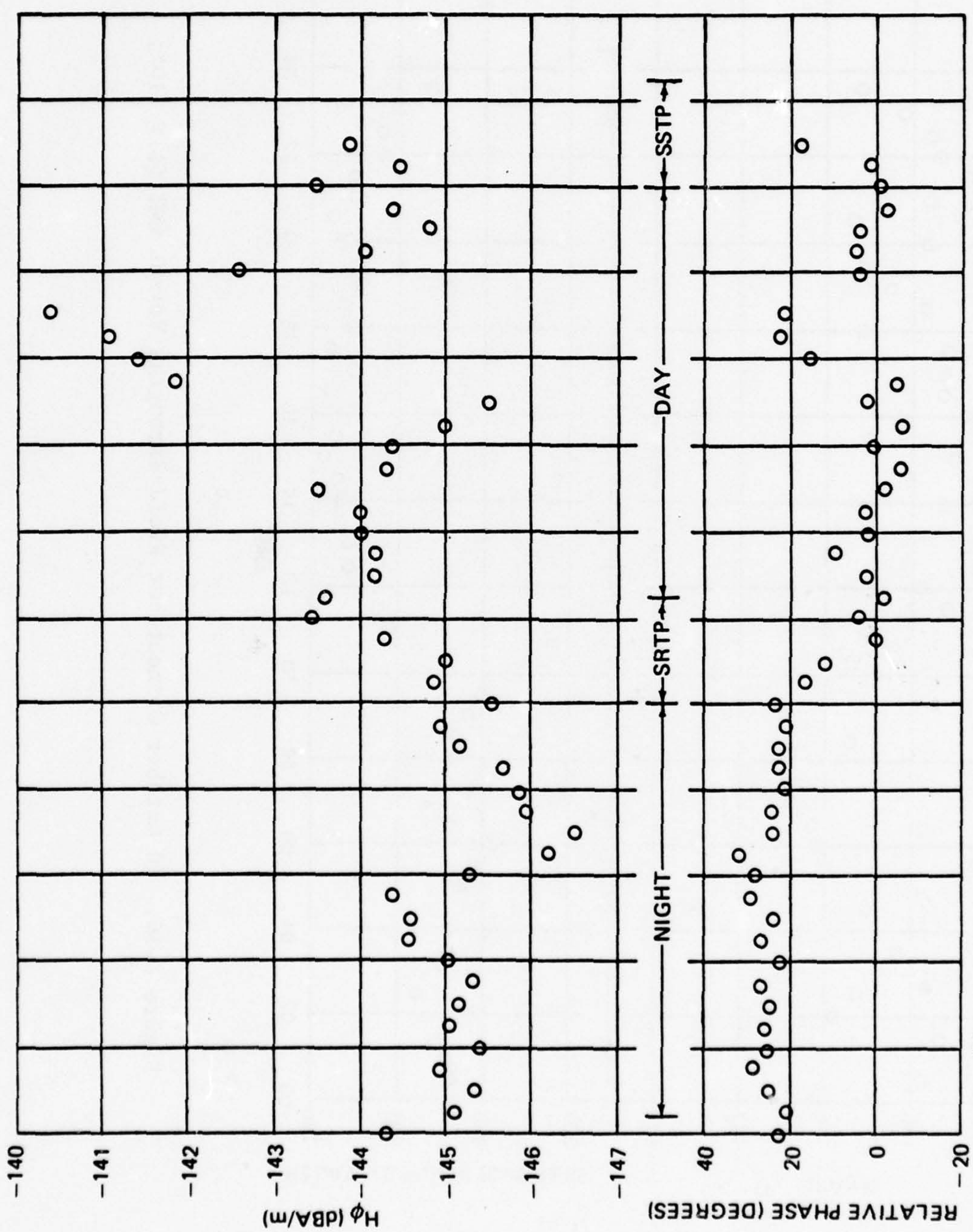


Figure A-35. 9 October Connecticut Field Strengths Versus GMT (ψ = 21°)

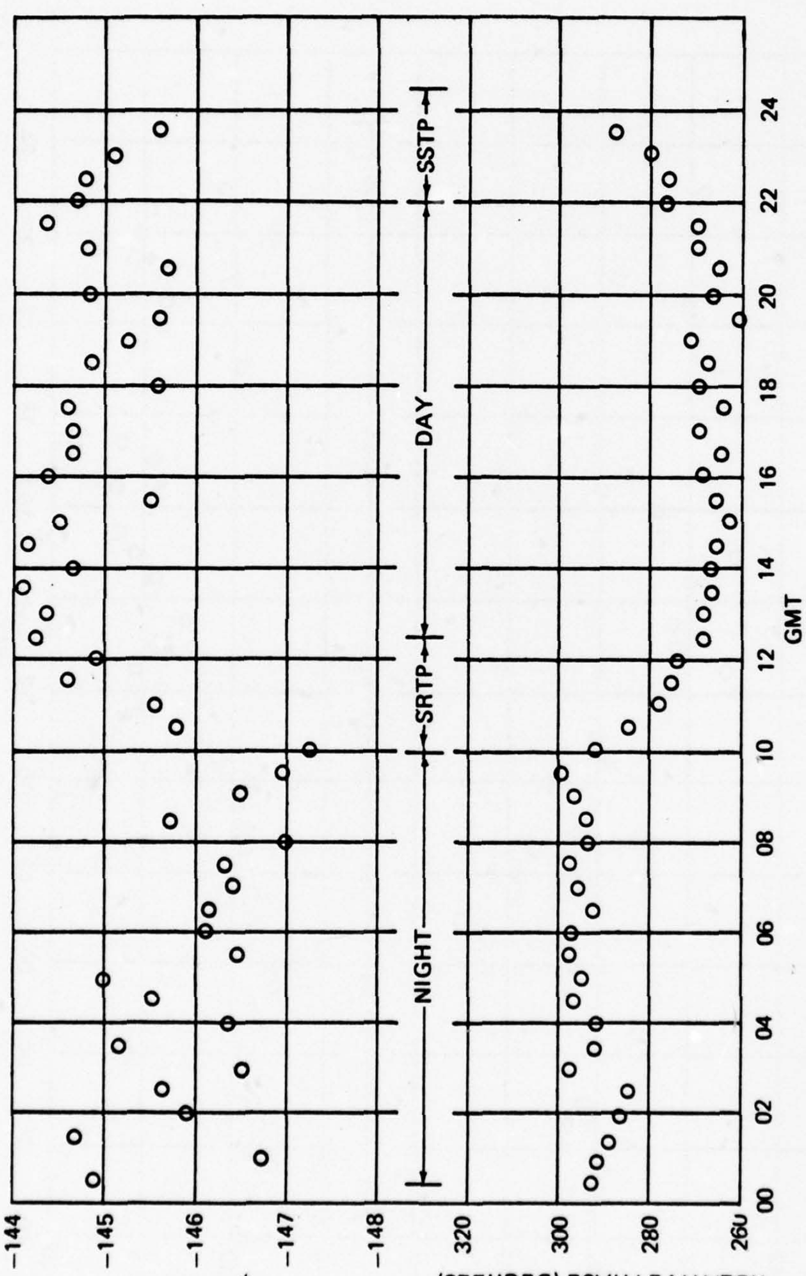


Figure A-36. 10 October Connecticut Field Strengths Versus GMT (ψ = 110°)

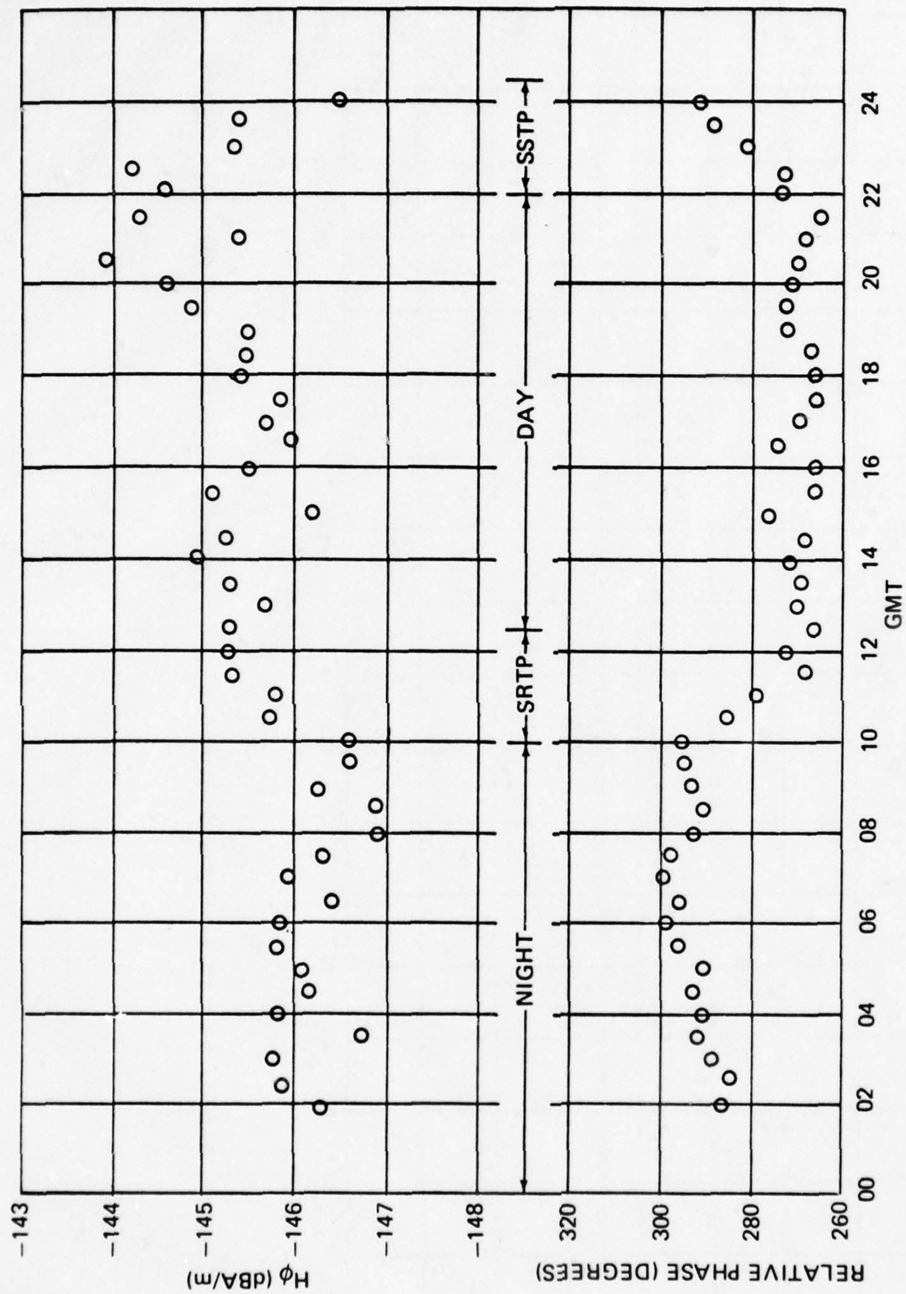


Figure A-37. 11 October Connecticut Field Strengths Versus GMT (ψ = 110°)

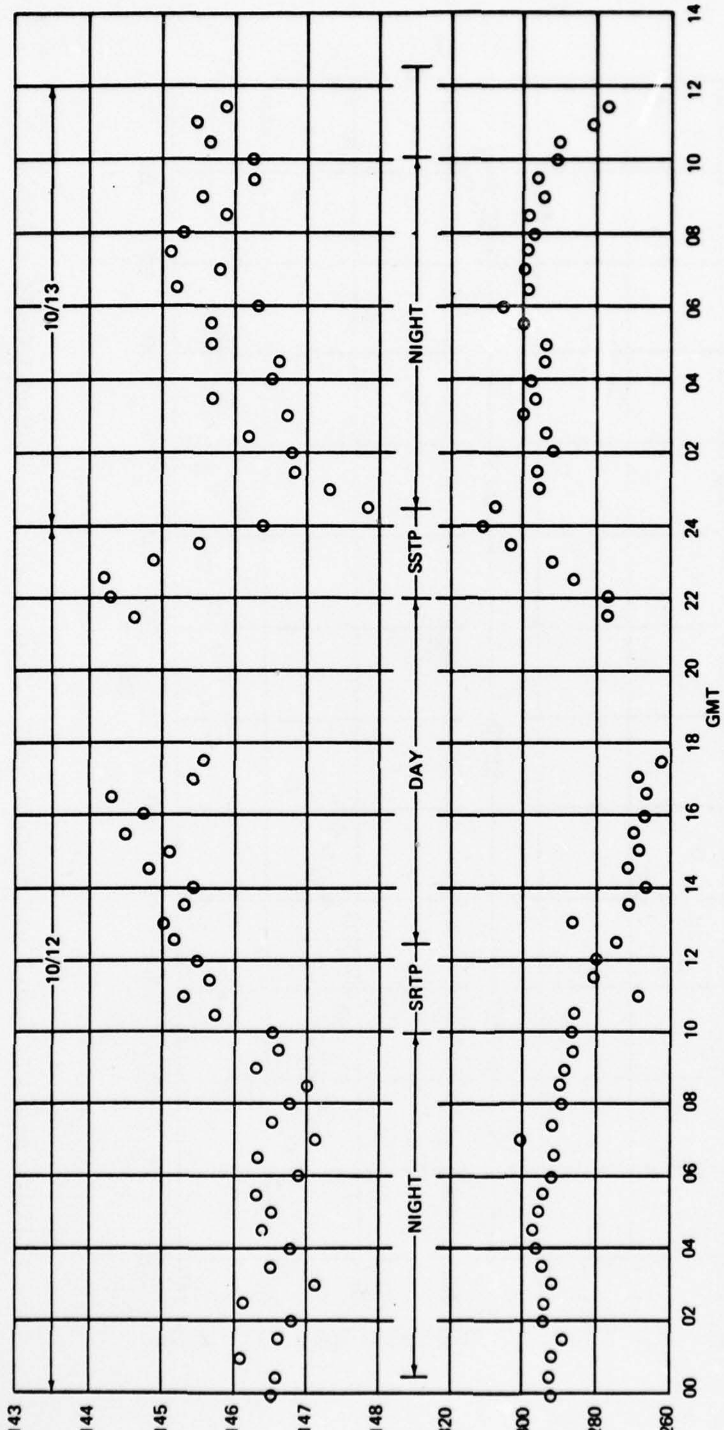


Figure A-38. 12 and 13 October Connecticut Field Strengths Versus GMT (ψ = 110°)

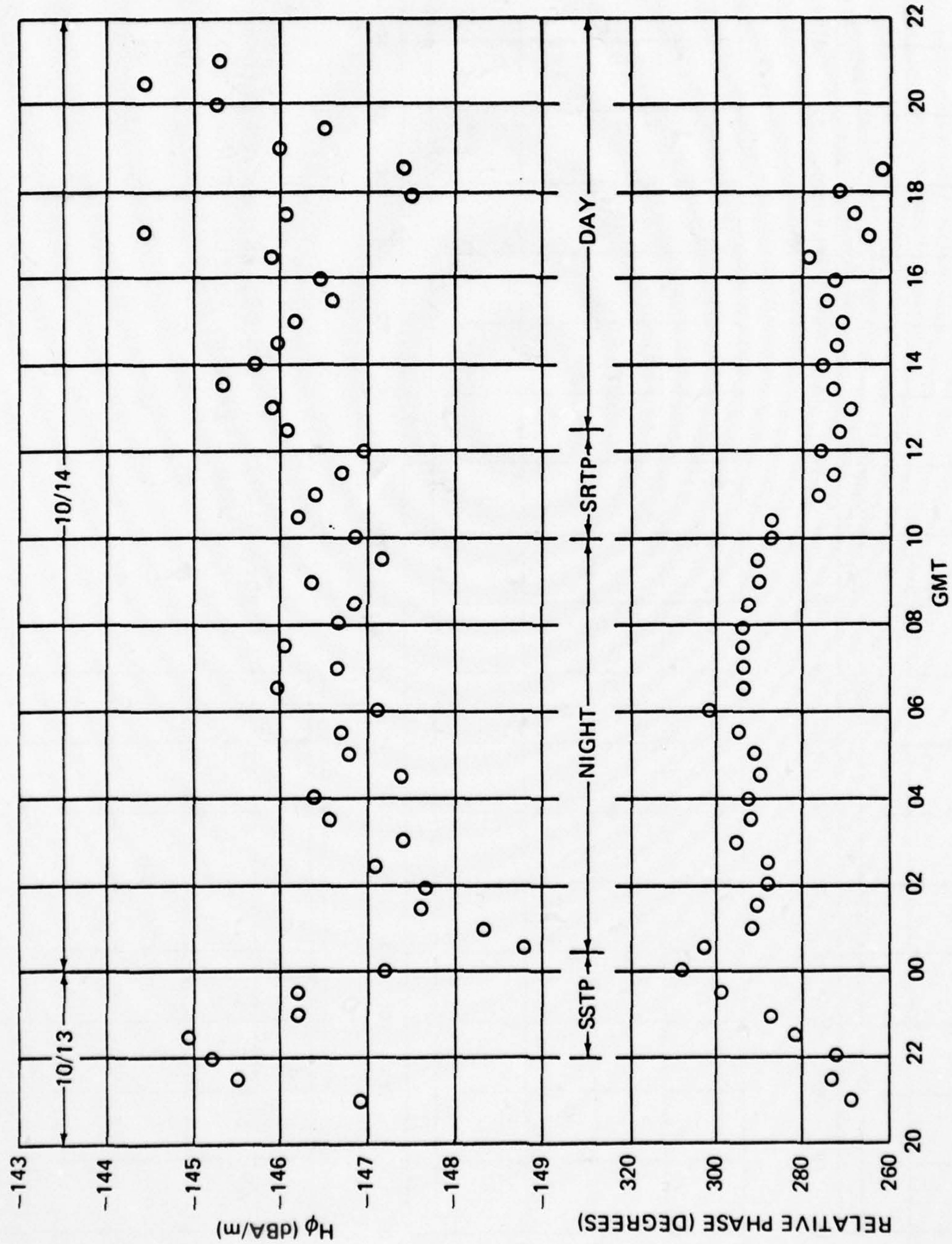
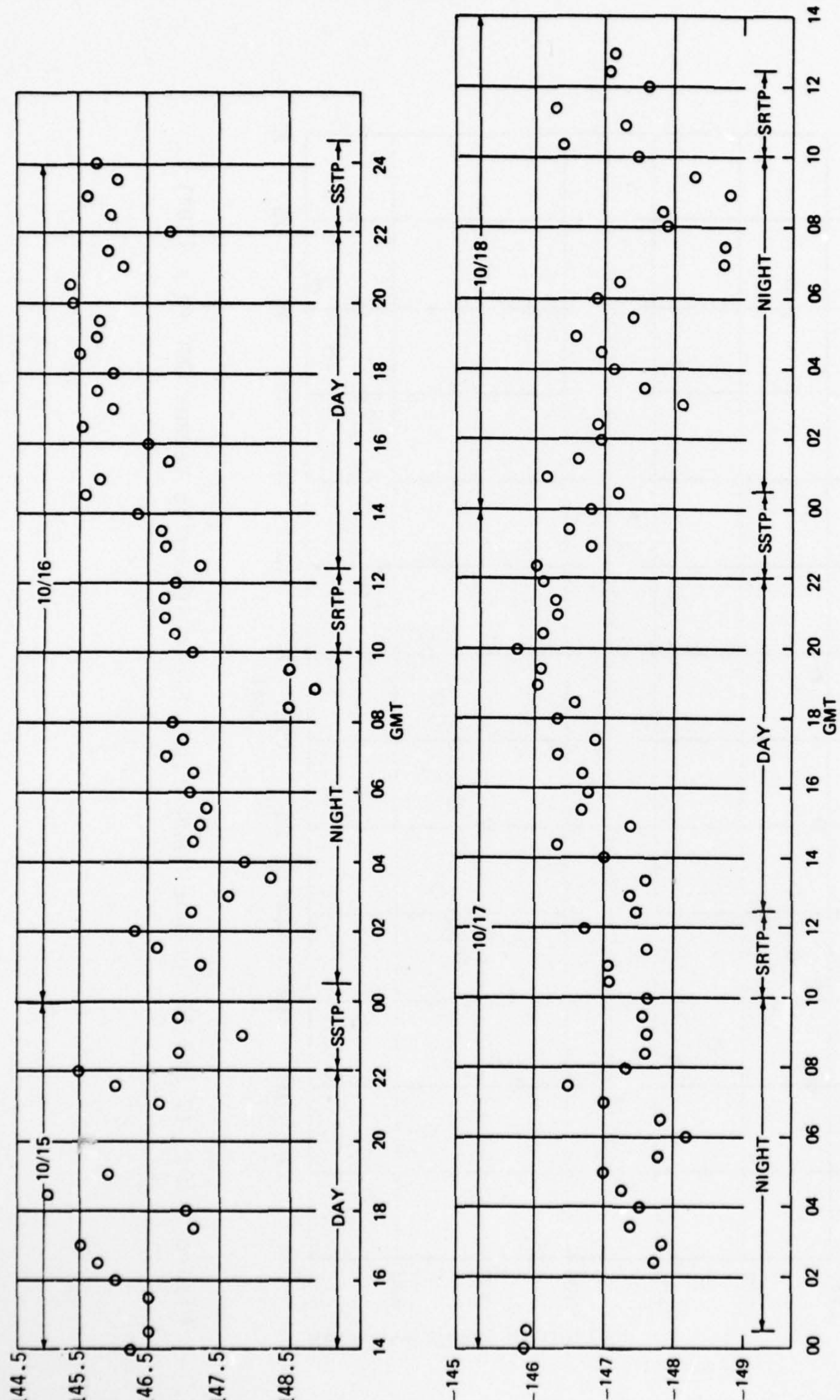


Figure A-39. 12 and 13 October Connecticut Field Strengths Versus GMT (ψ = 110°)



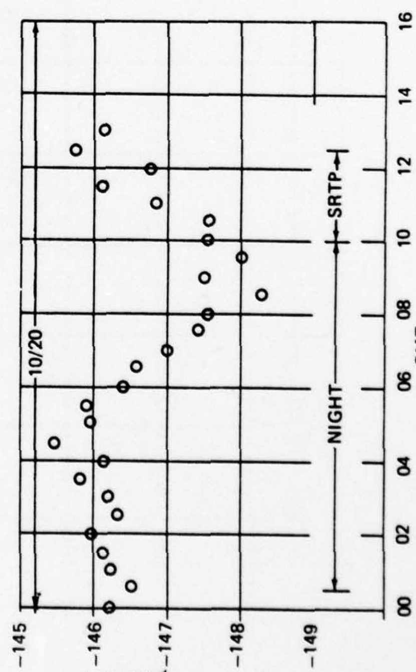


Figure A-40. 15, 16, 17, 18, and 20 October Connecticut Field Strengths Versus GMT (ψ = 110°)

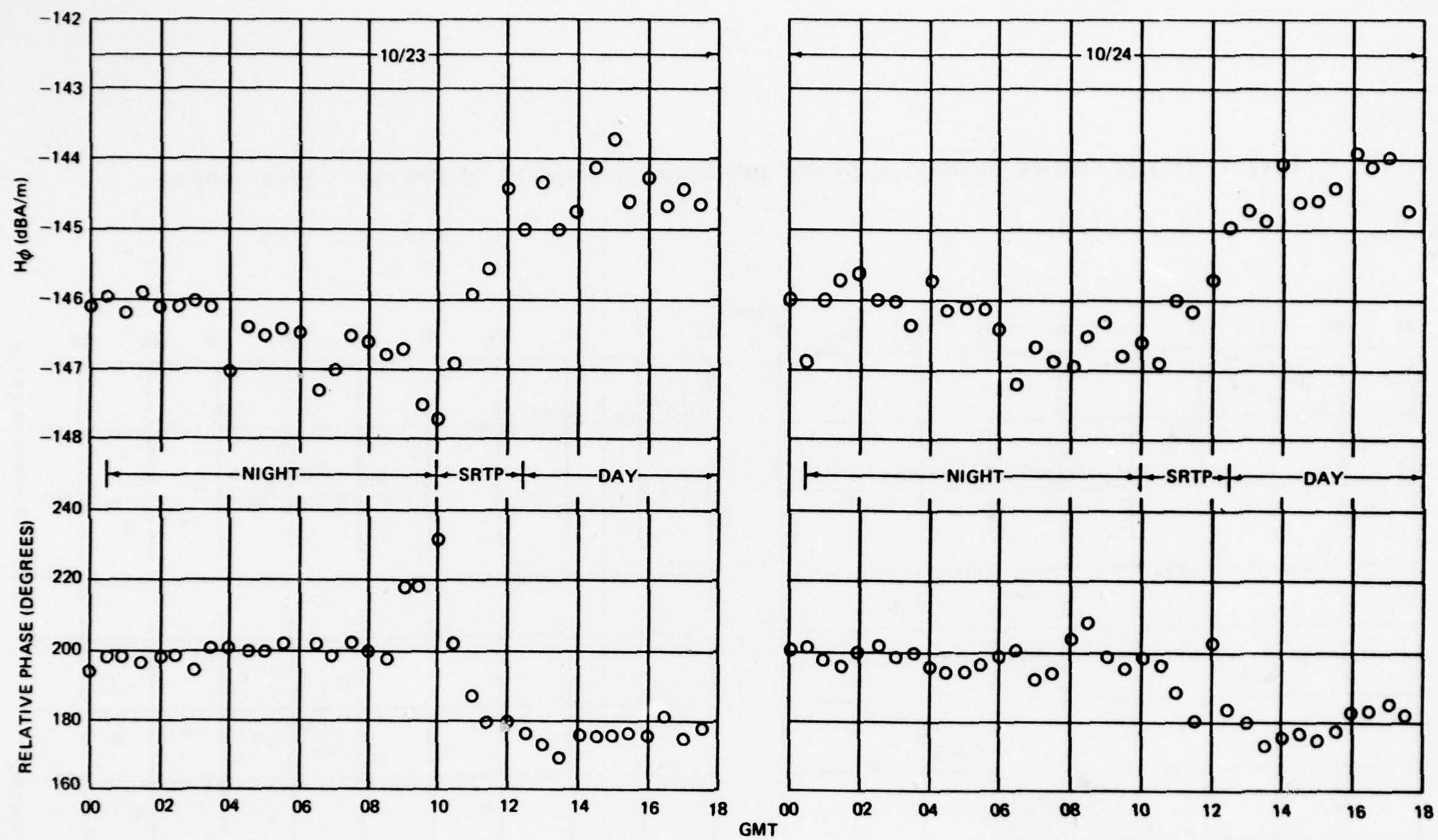


Figure A-41. 23 and 24 October Connecticut Field Strengths Versus GMT (ψ = 21°)

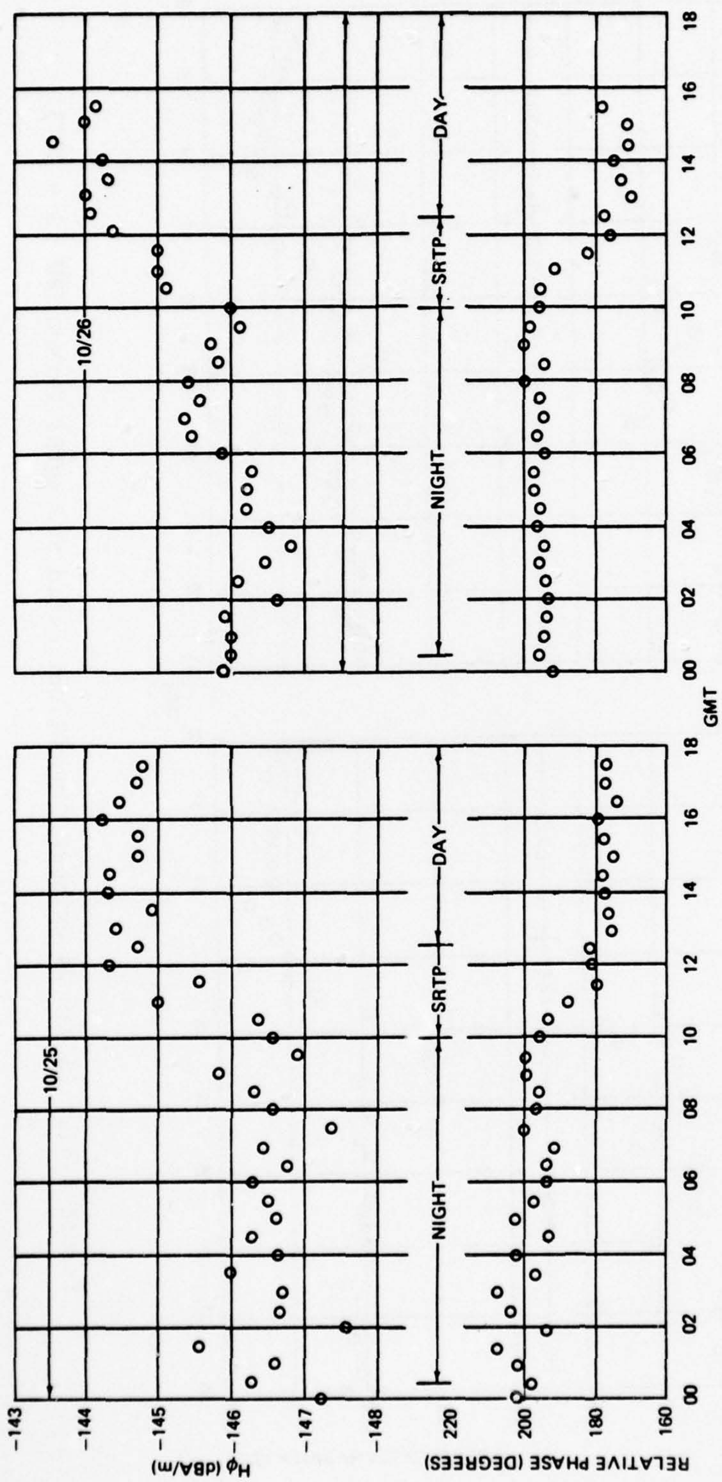


Figure A-42. 25 and 26 October Connecticut Field Strengths Versus GMT ($\psi = 21°$)

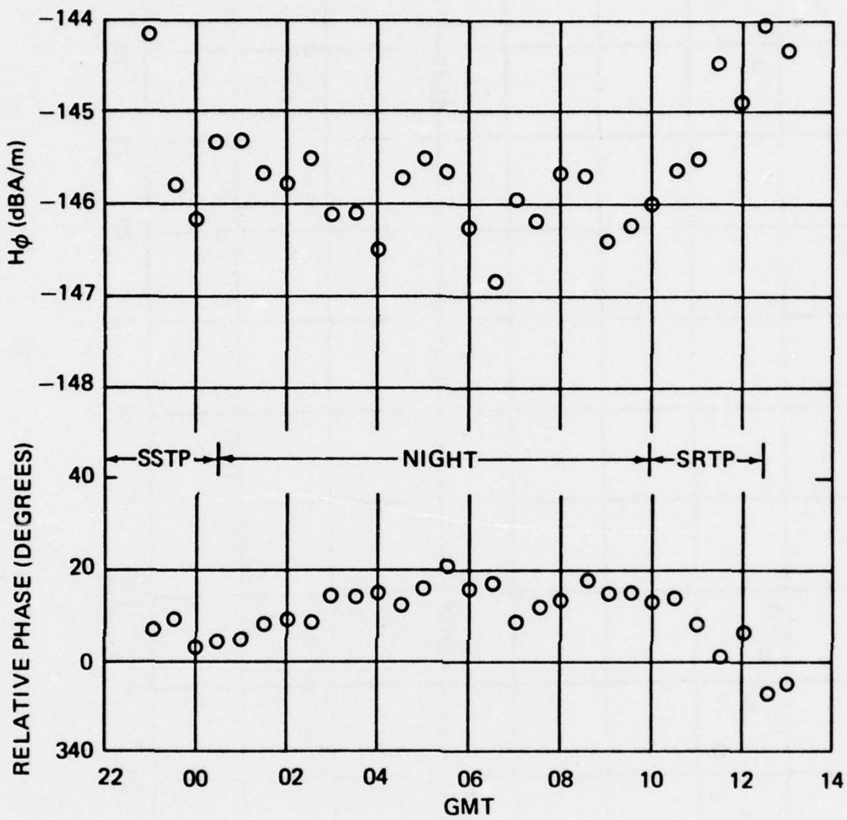


Figure A-43. 27 October Connecticut Field Strengths Versus GMT (ψ = 21°)

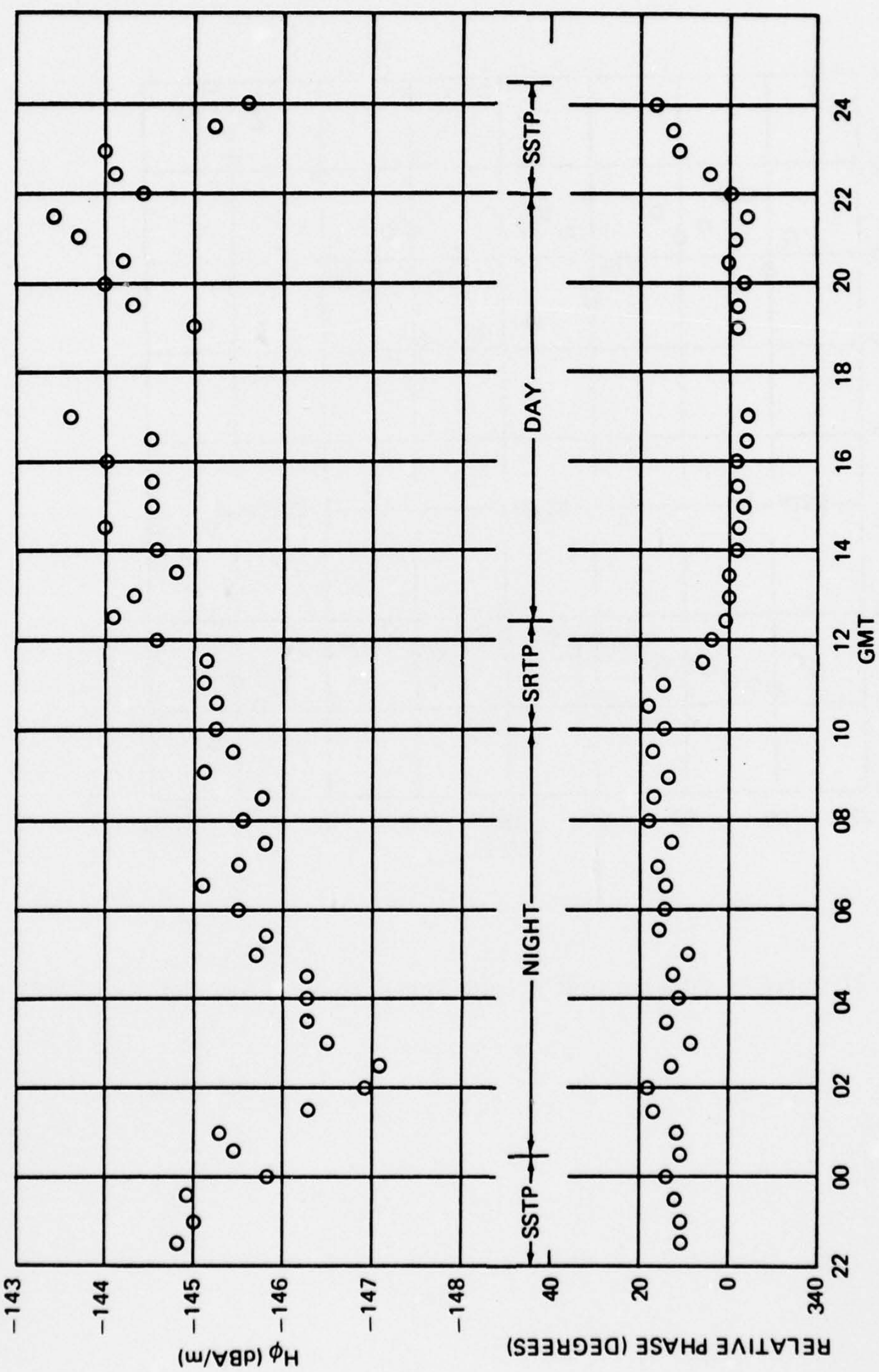


Figure A-44. 28 October Connecticut Field Strengths Versus GMT (ψ = 21°)

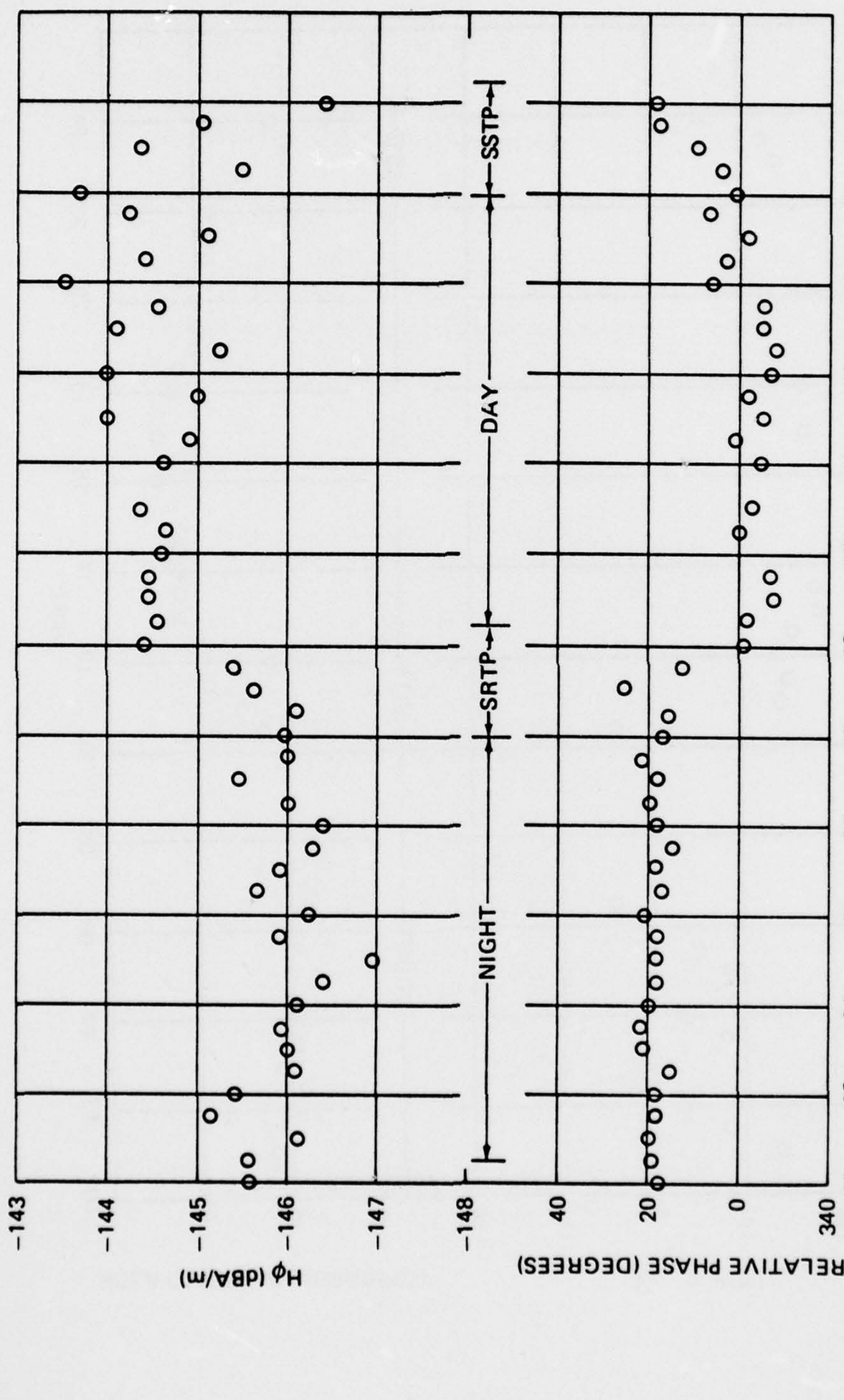


Figure A-45. 29 October Connecticut Field Strength Versus GMT (ψ = 21°)

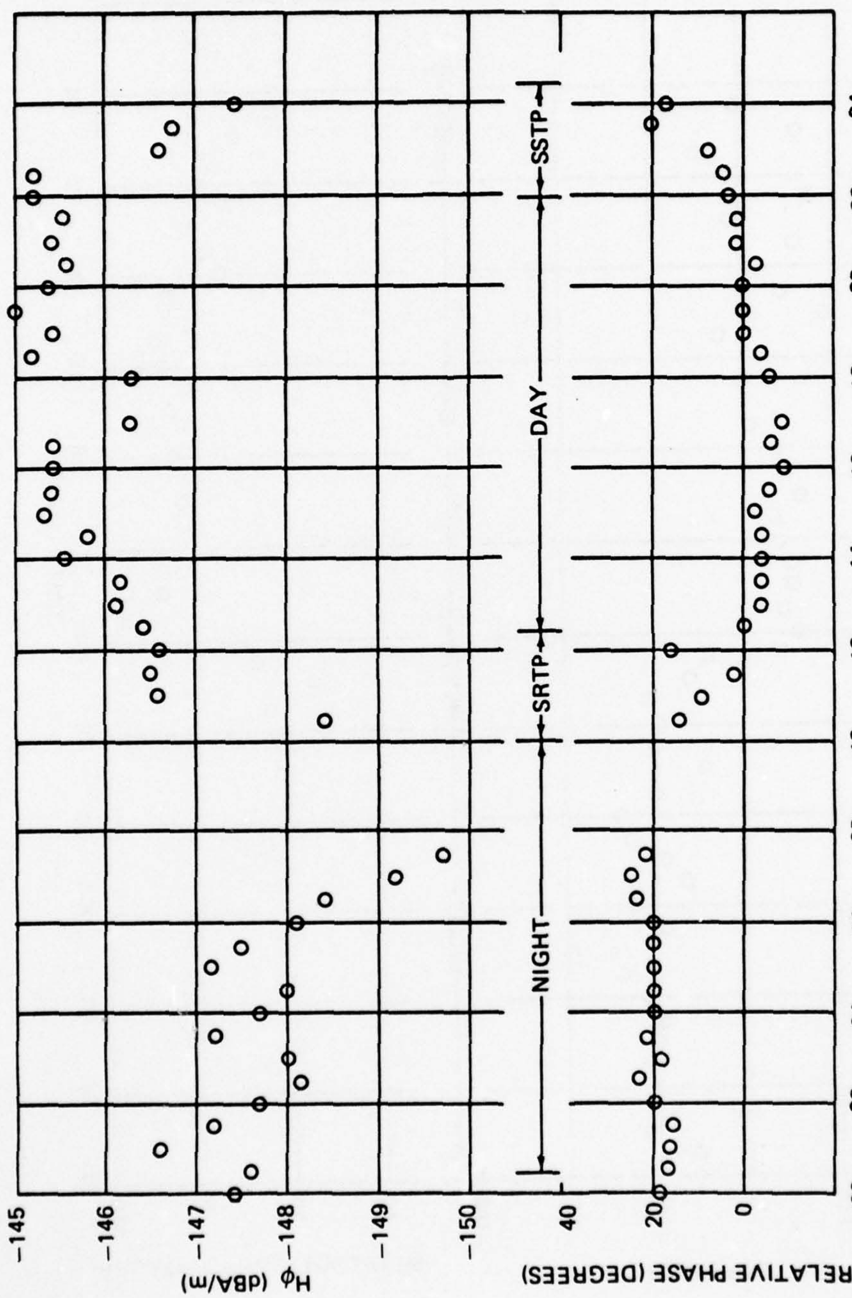


Figure A-46. 30 October Connecticut Field Strengths Versus GMT (ψ = 21°)

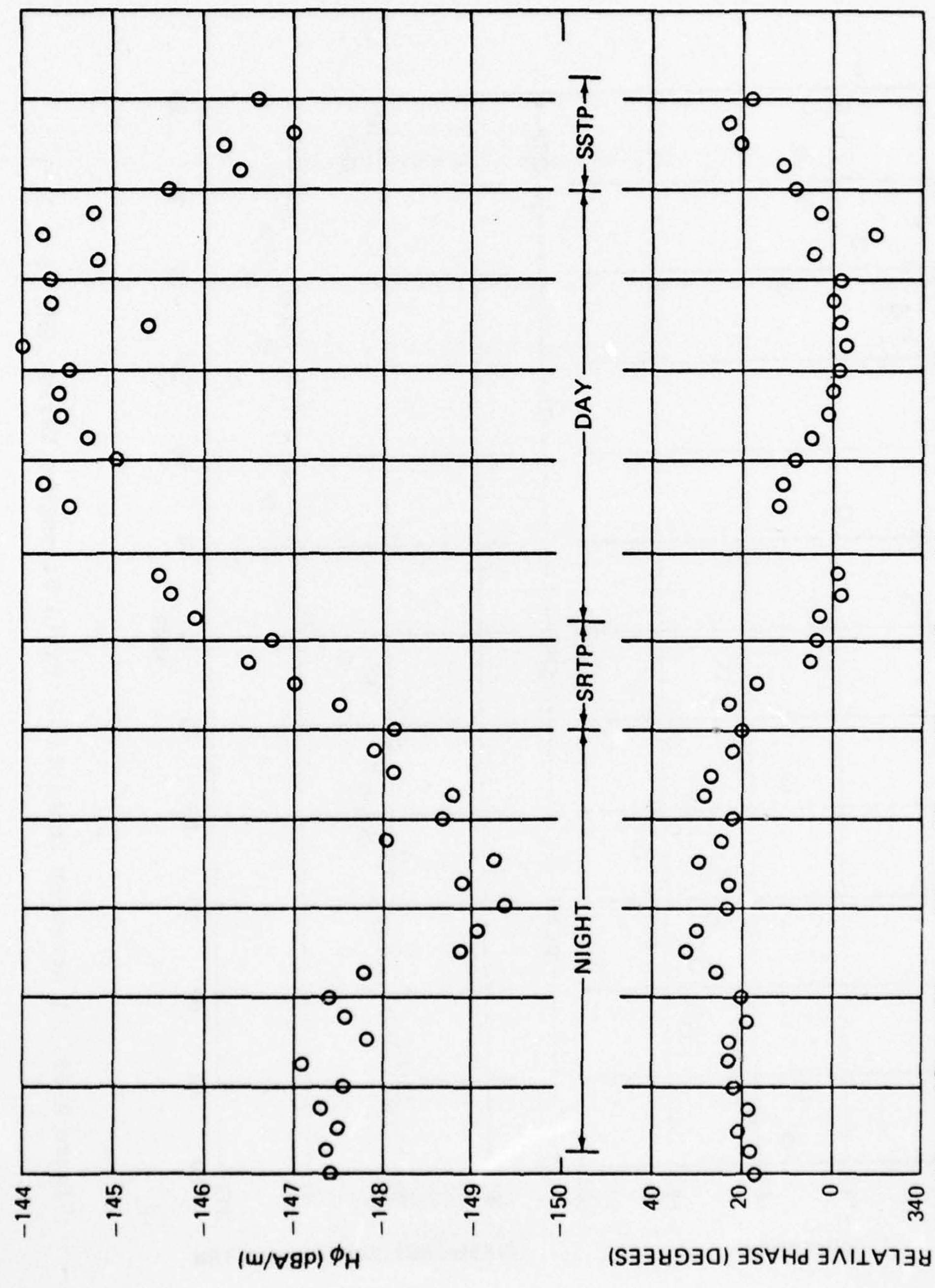


Figure A-47. 31 October Connecticut Field Strengths Versus GMT (ψ = 21°)

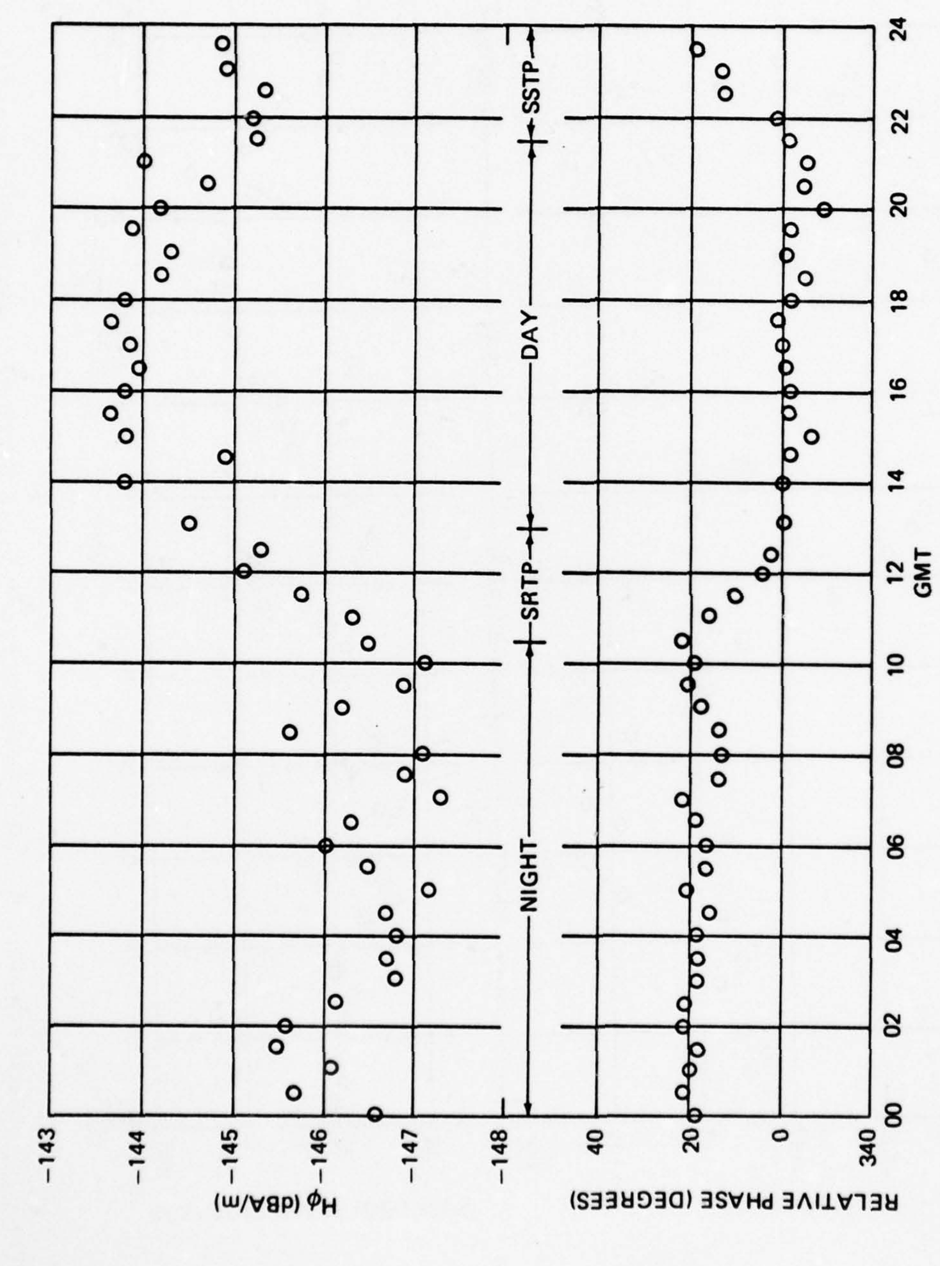


Figure A-48. 1 November Connecticut Field Strengths Versus GMT (ψ = 21°)

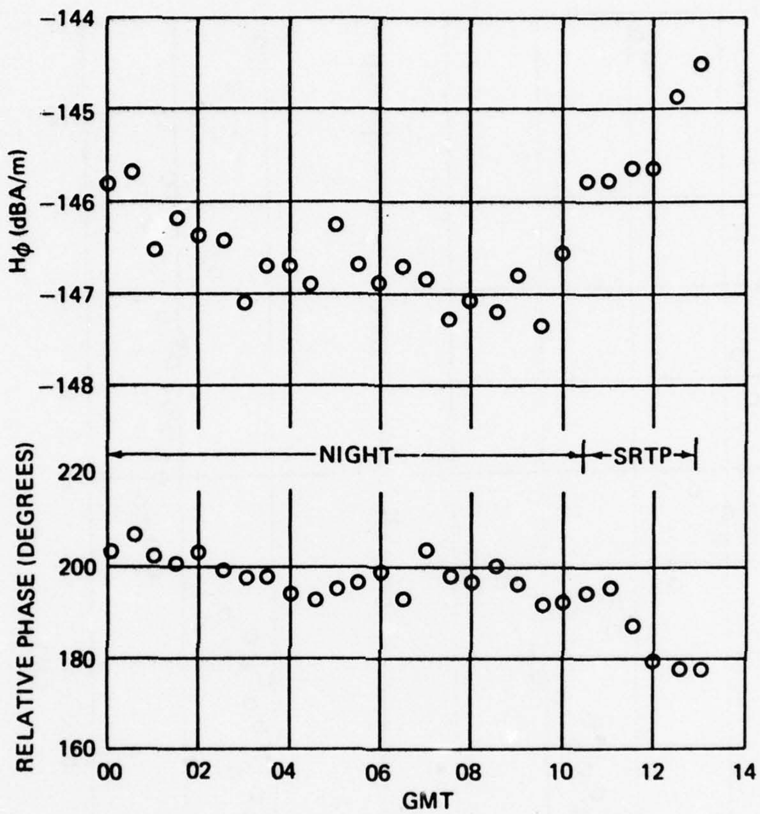


Figure A-49. 2 November Connecticut Field Strengths Versus GMT (ψ = 21°)

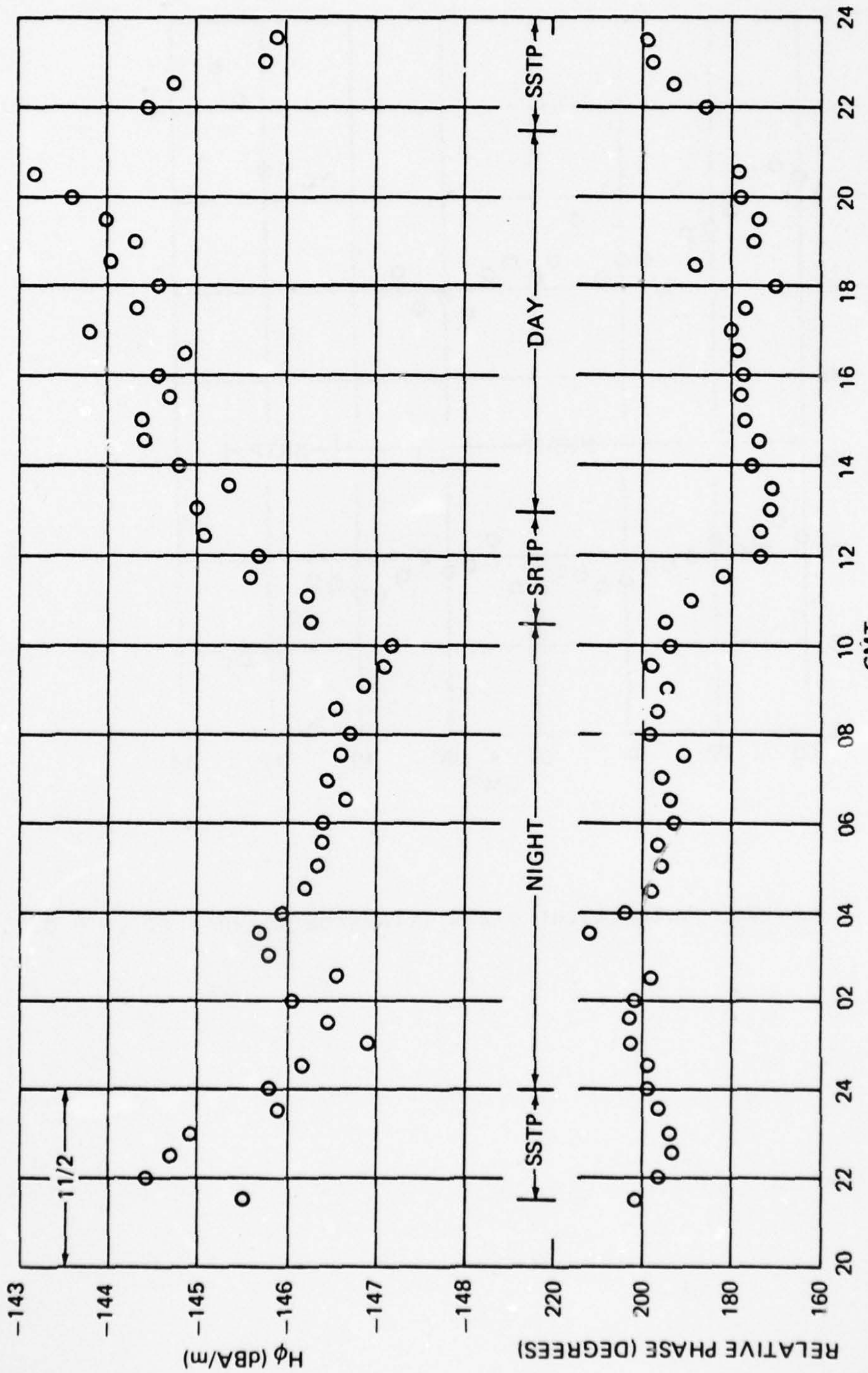


Figure A-50. 2 and 3 November Connecticut Field Strengths Versus GMT (ψ = 21°)

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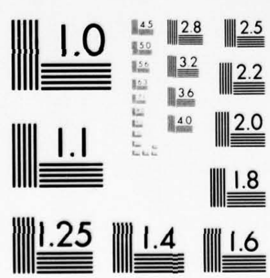

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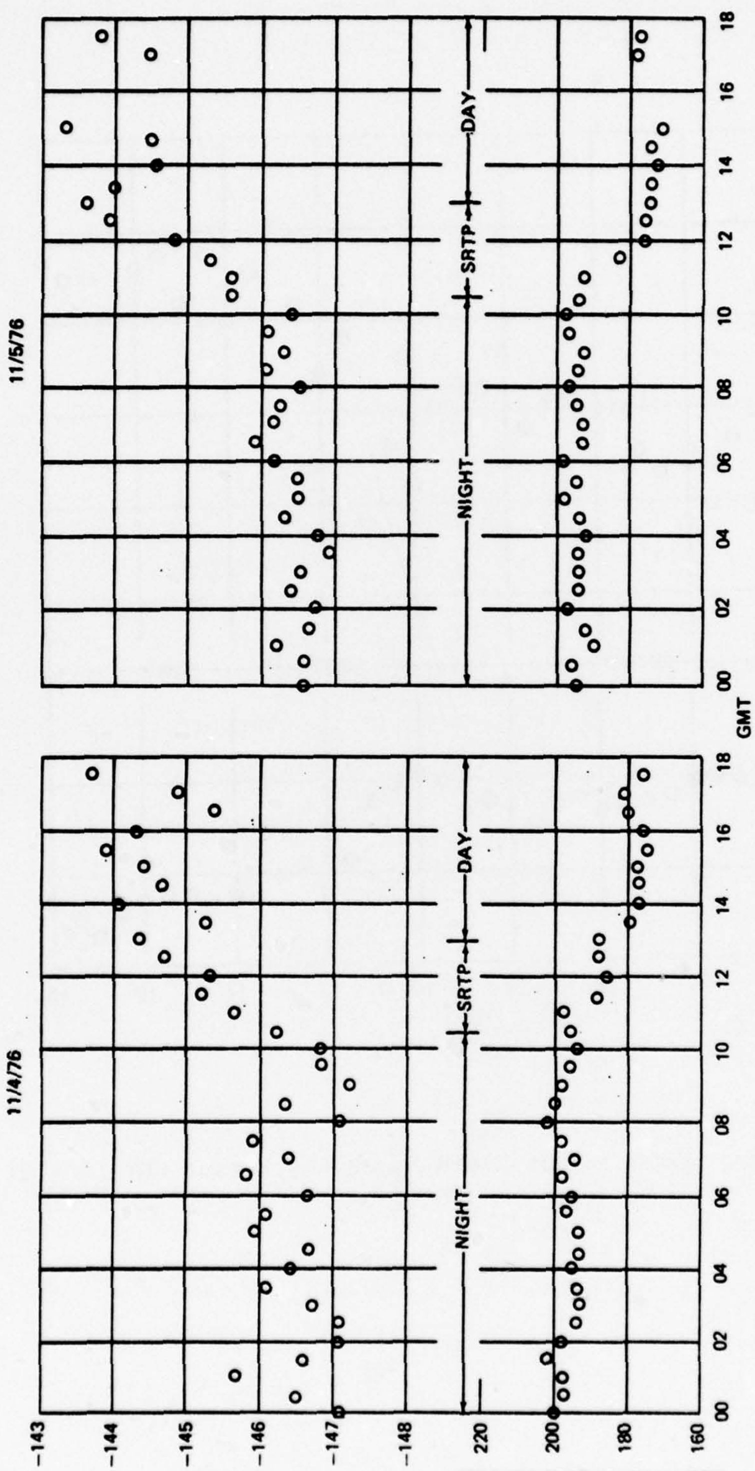

Figure A-51. 4 and 5 November Connecticut Field Strengths Versus GMT (ψ = 21°)

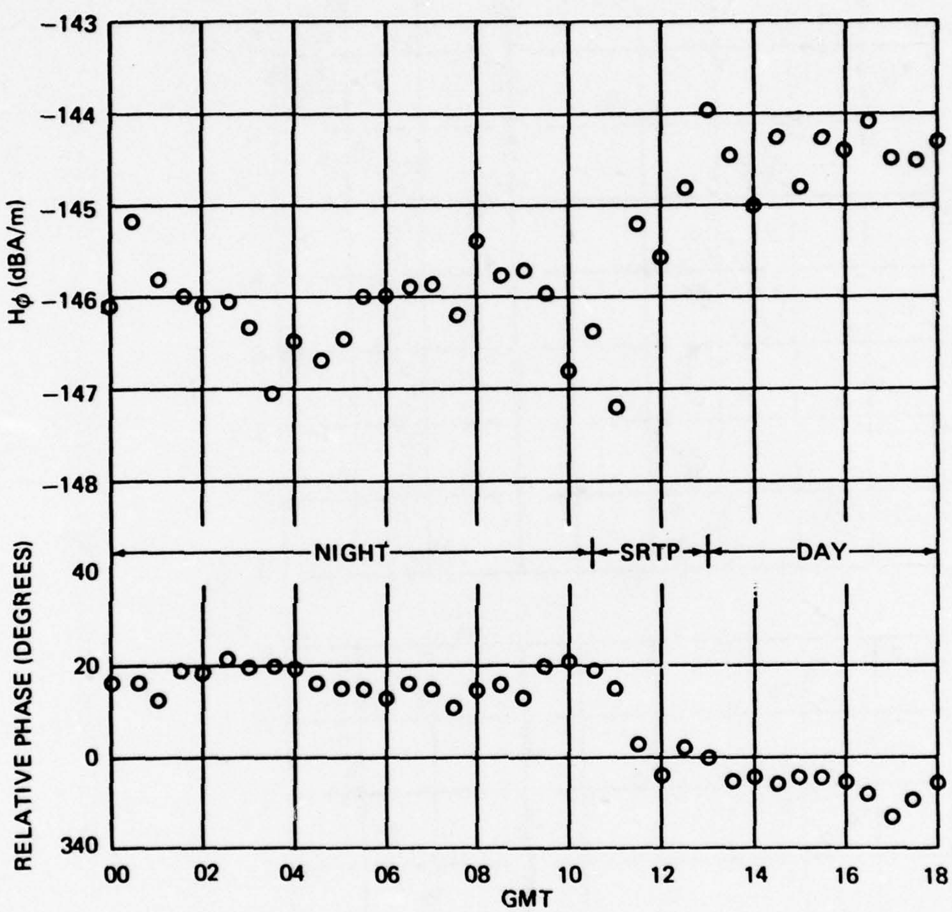

Figure A-52. 6 November Connecticut Field Strengths Versus GMT (ψ = 21°)

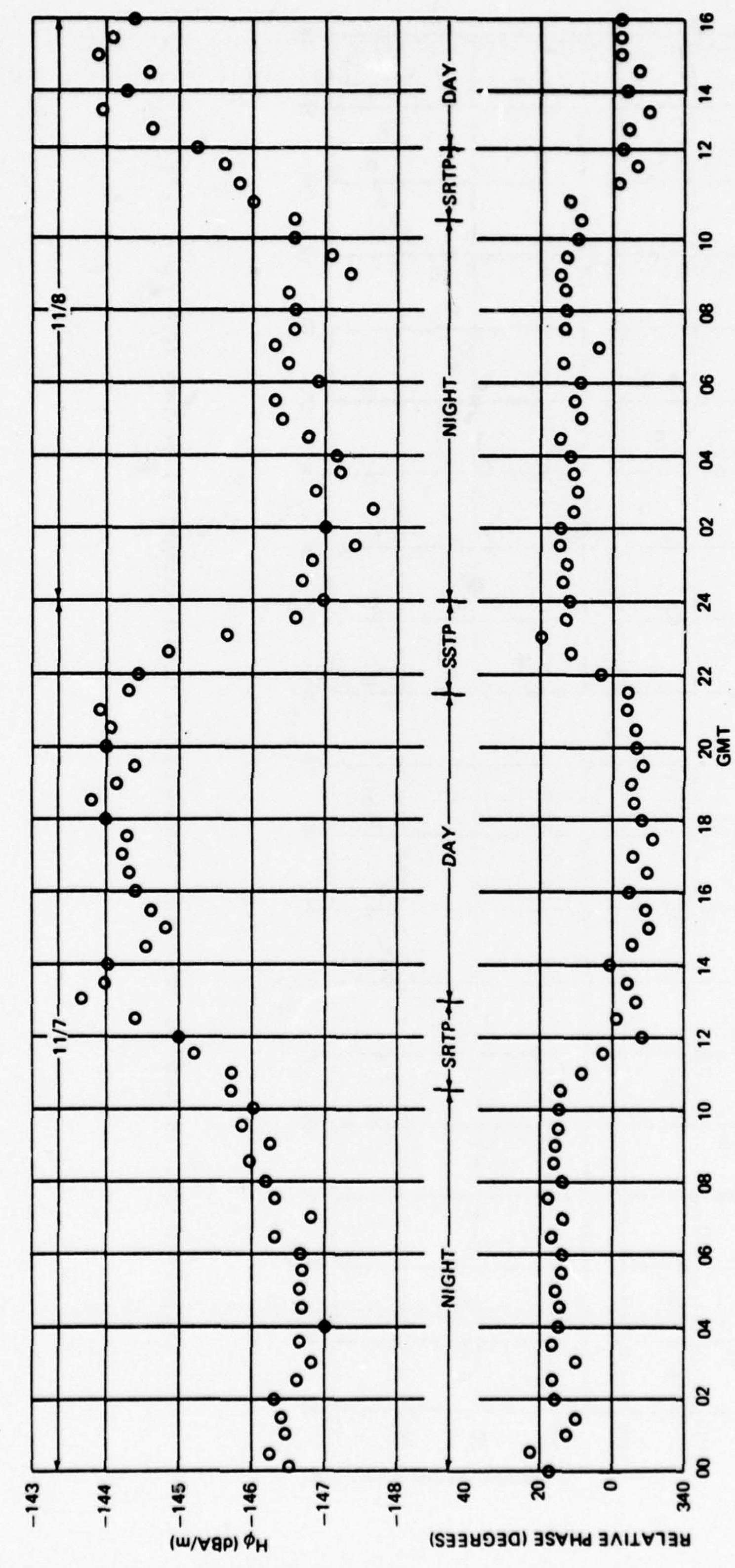

Figure A-53. 7 and 8 November Connecticut Field Strengths Versus GMT (ψ = 21°)

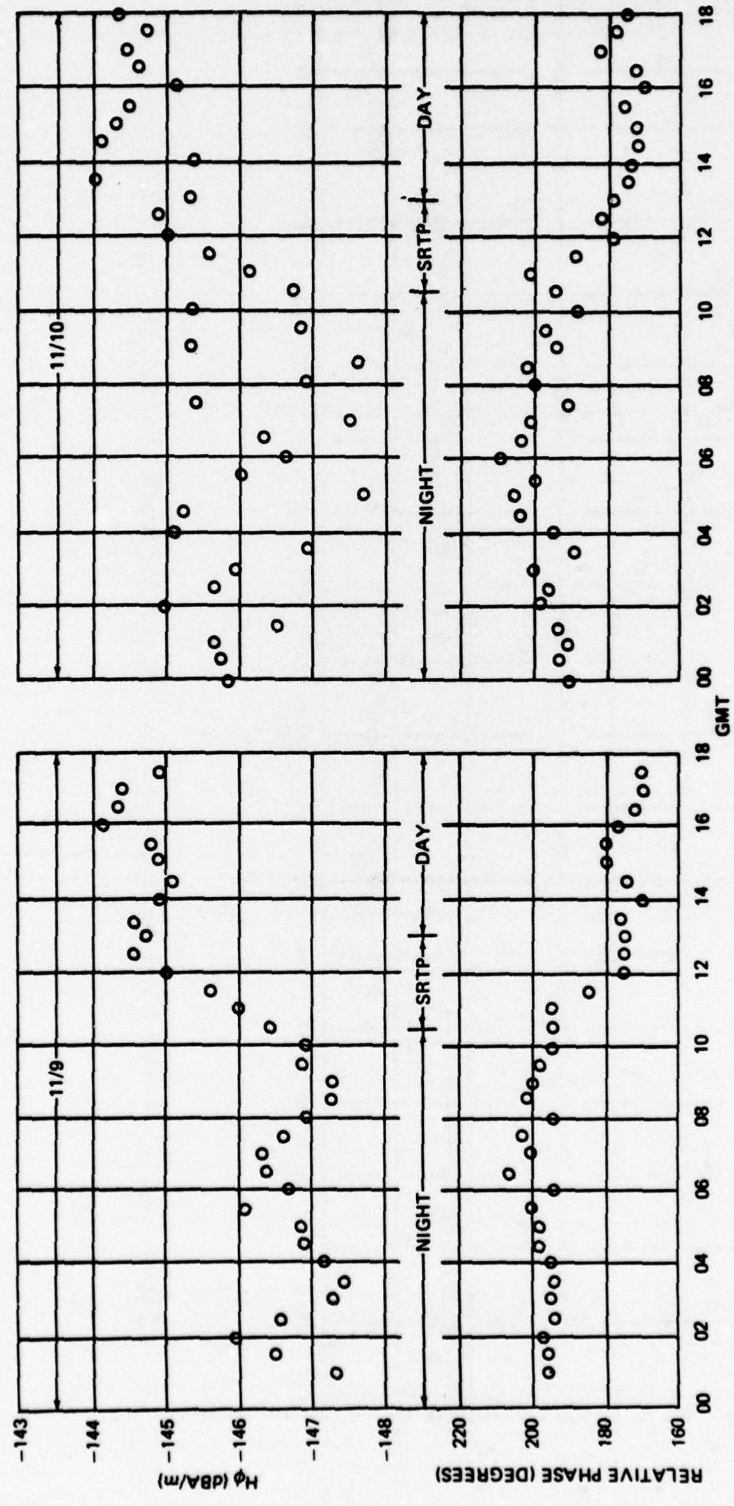

Figure A-54. 9 and 10 November Connecticut Field Strengths Versus GMT (ψ = 21°)

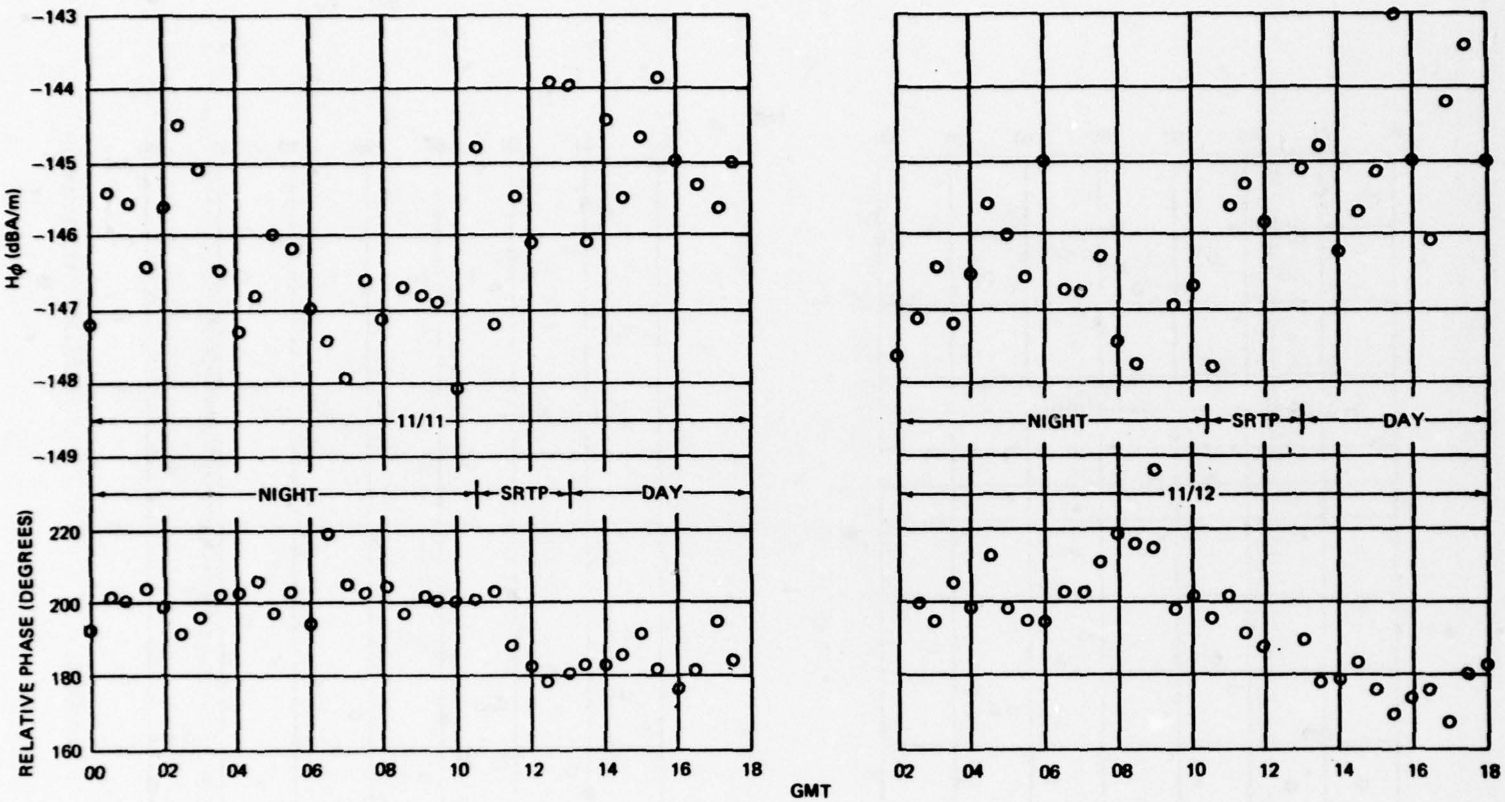

Figure A-55. 11 and 12 November Connecticut Field Strengths Versus GMT (ψ = 21°)

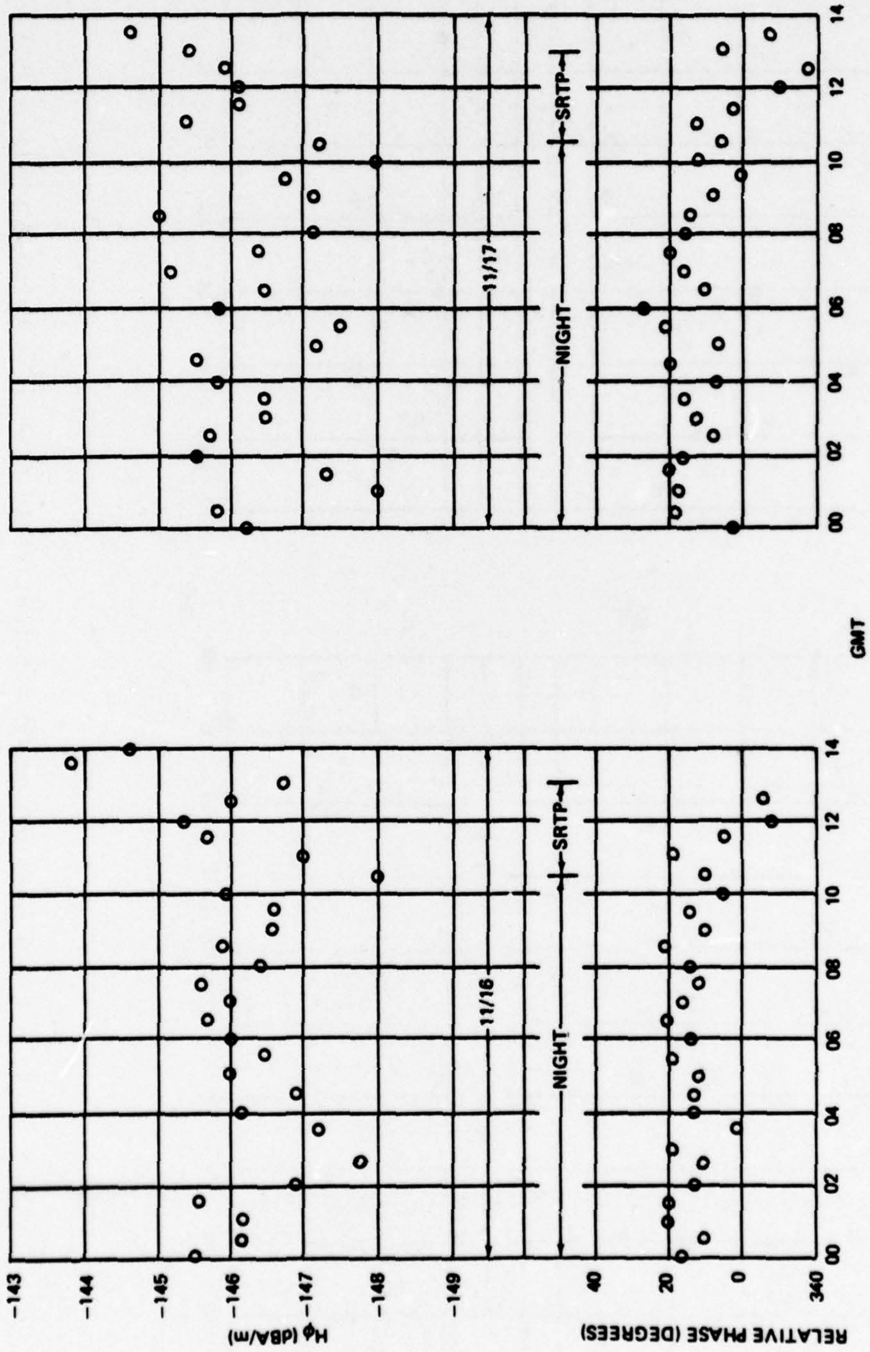

Figure A-56. 16 and 17 November Connecticut Field Strengths Versus GMT (ψ = 21°)

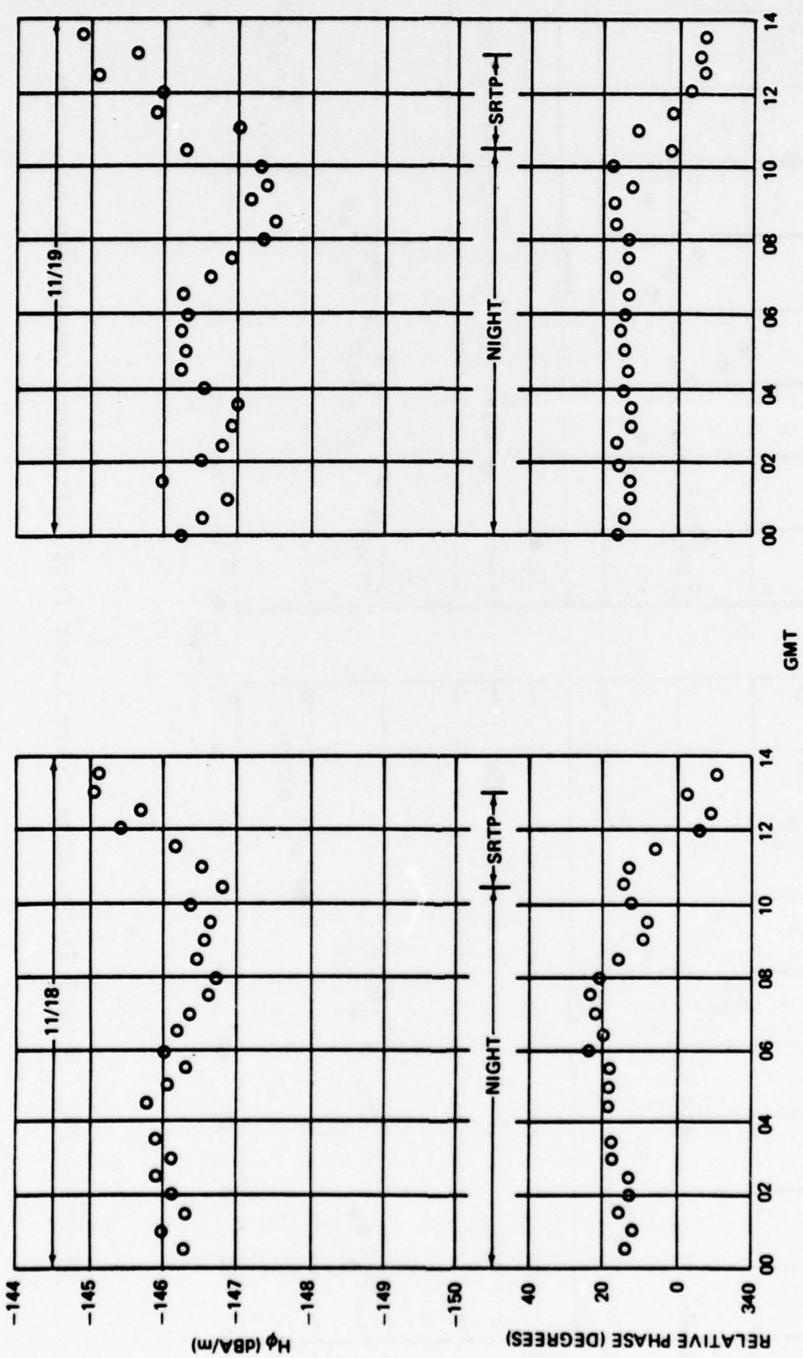

Figure A-57. 18 and 19 November Connecticut Field Strengths Versus GMT (ψ = 21°)

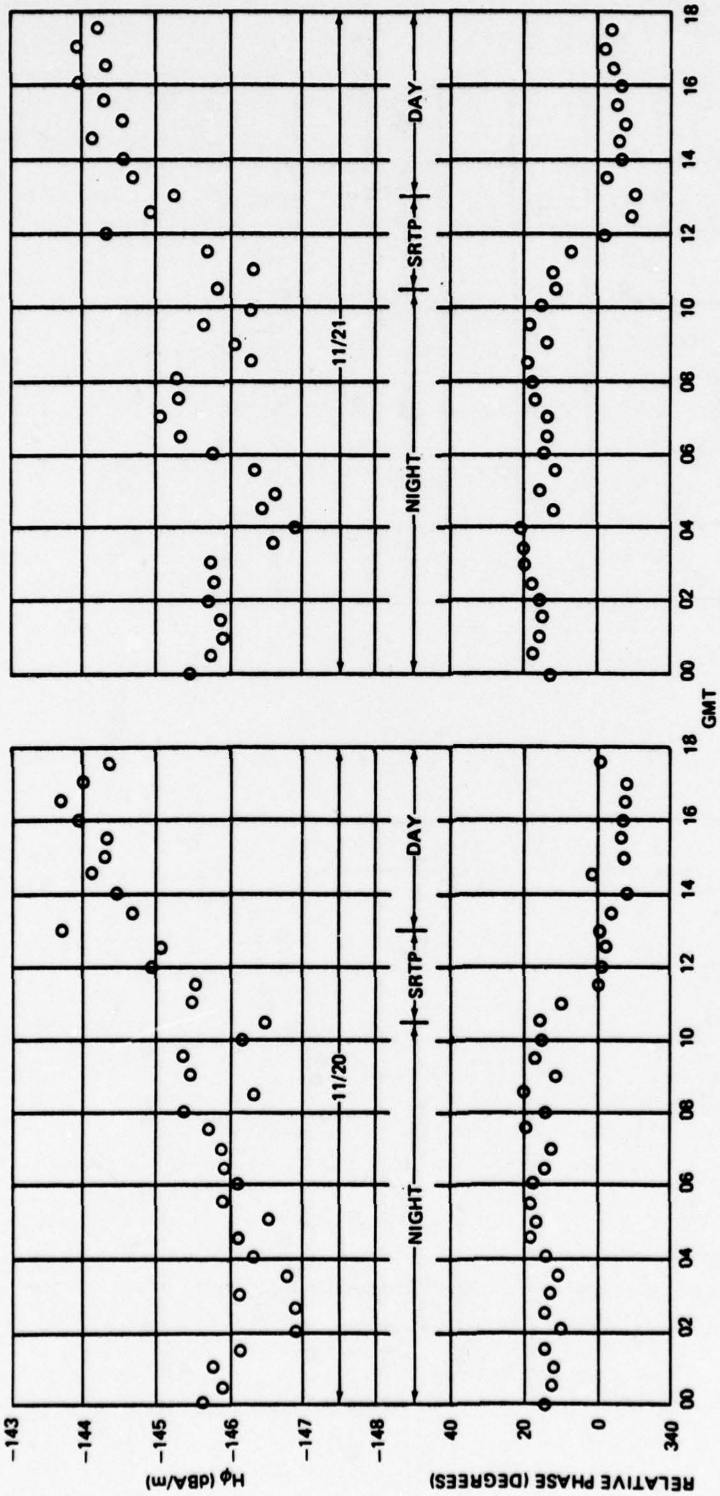

Figure A-58. 20 and 21 November Connecticut Field Strengths Versus GMT (ψ = 21°)

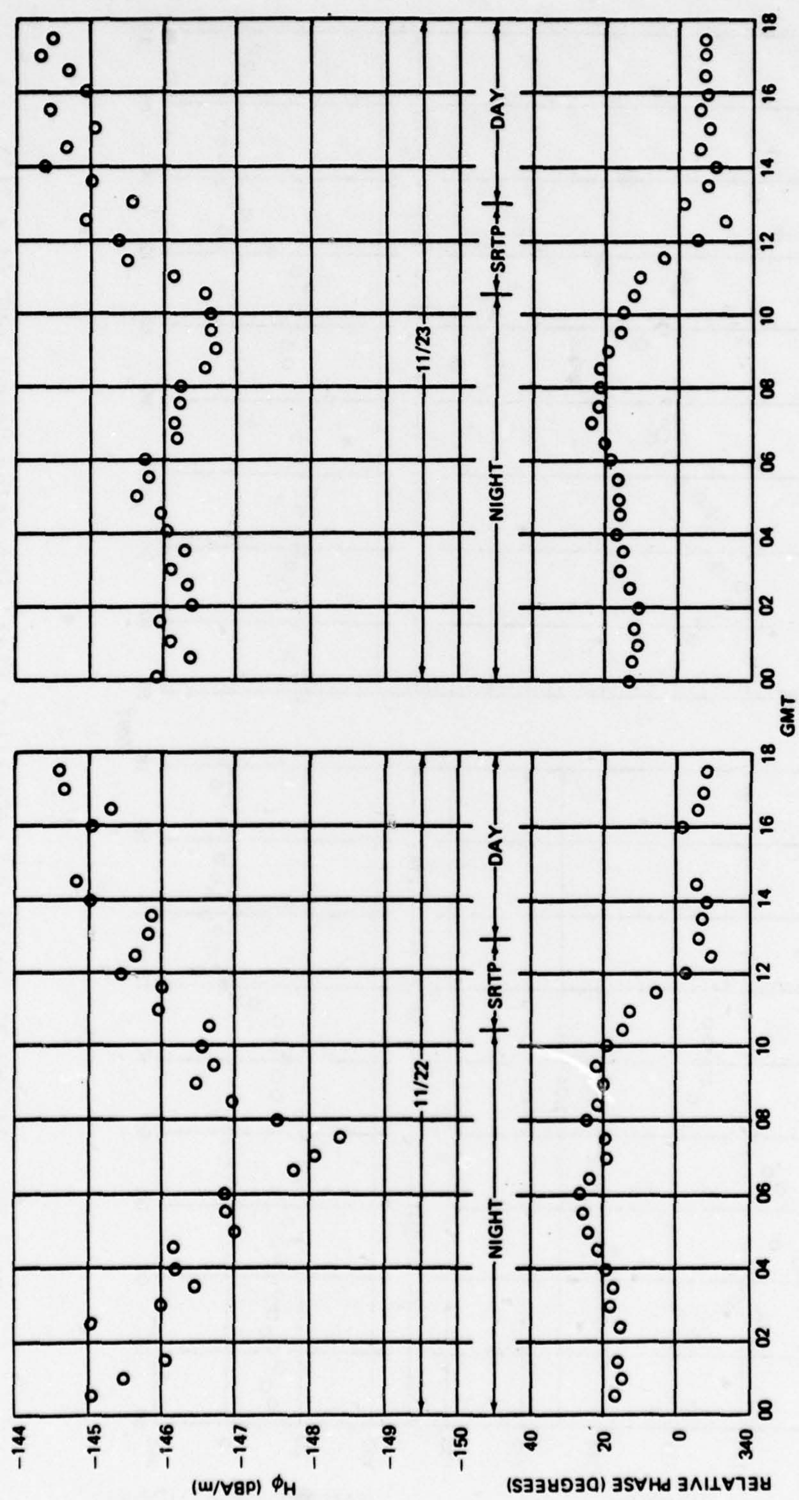

Figure A-59. 22 and 23 November Connecticut Field Strengths Versus GMT (ψ = 21°)

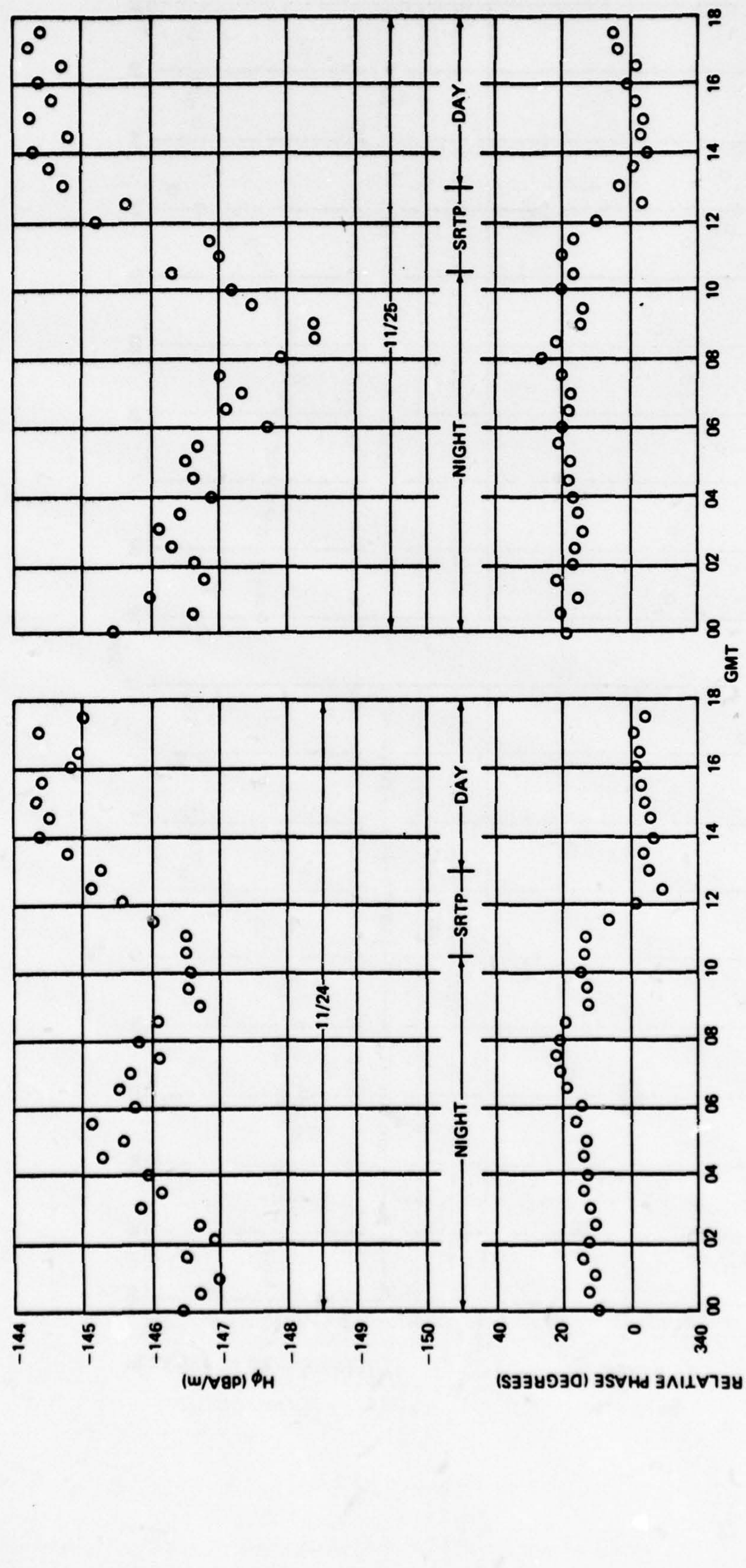

Figure A-60. 24 and 25 November Connecticut Field Strengths Versus GMT (ψ = 21°)

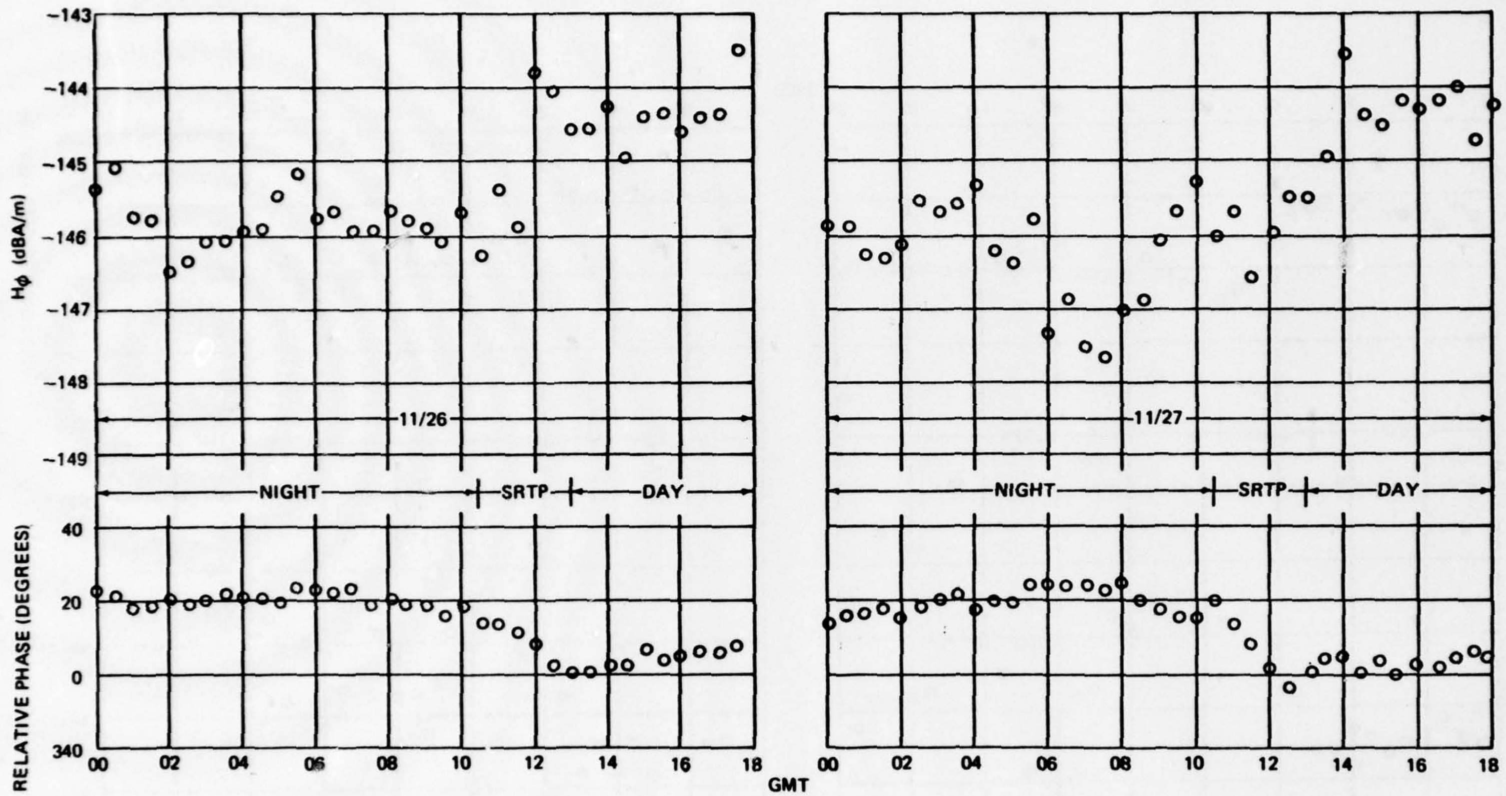

Figure A-61. 26 and 27 November Connecticut Field Strengths Versus GMT (ψ = 21°)

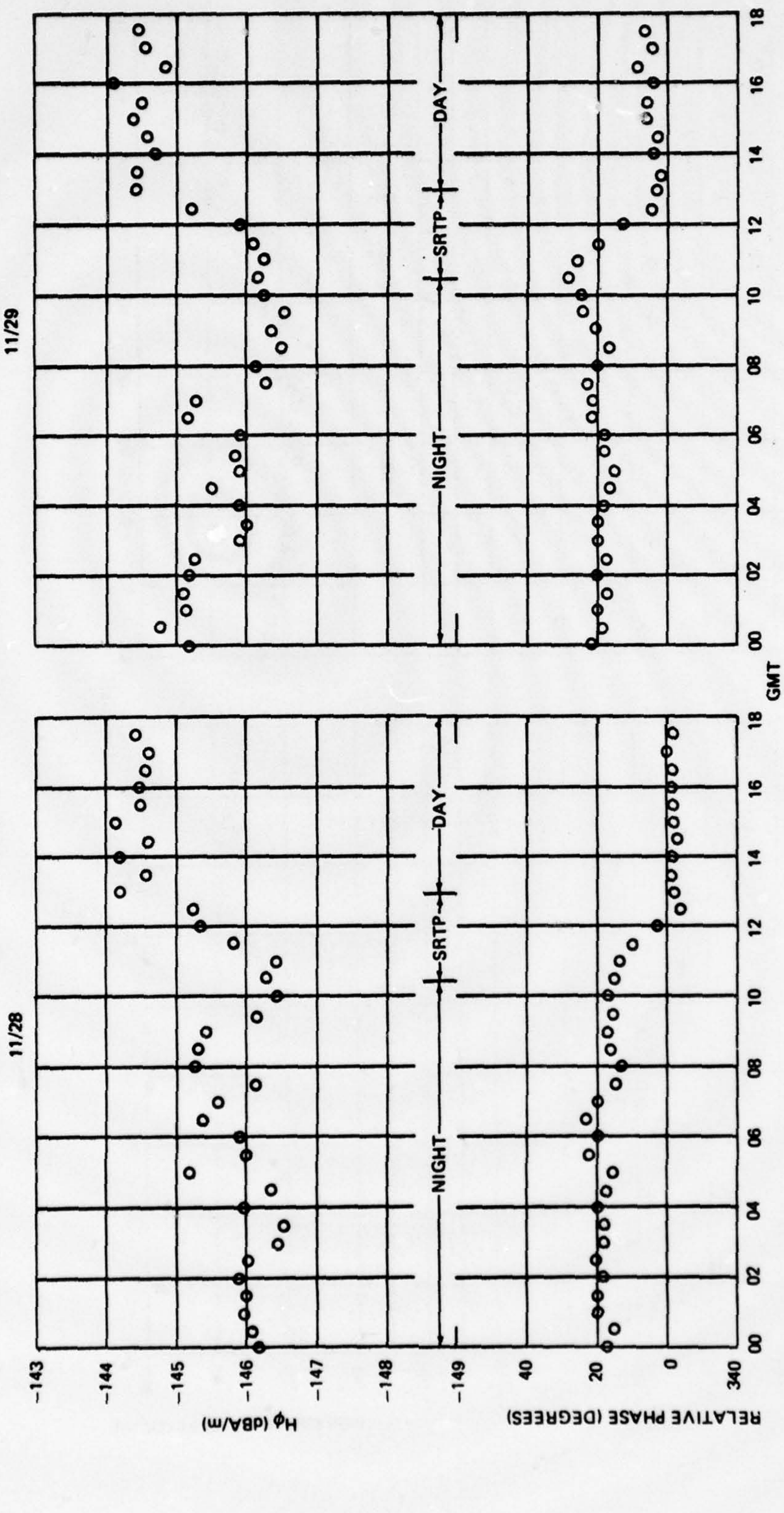

Figure A-62. 28 and 29 November Connecticut Field Strengths Versus GMT (ψ = 21°)

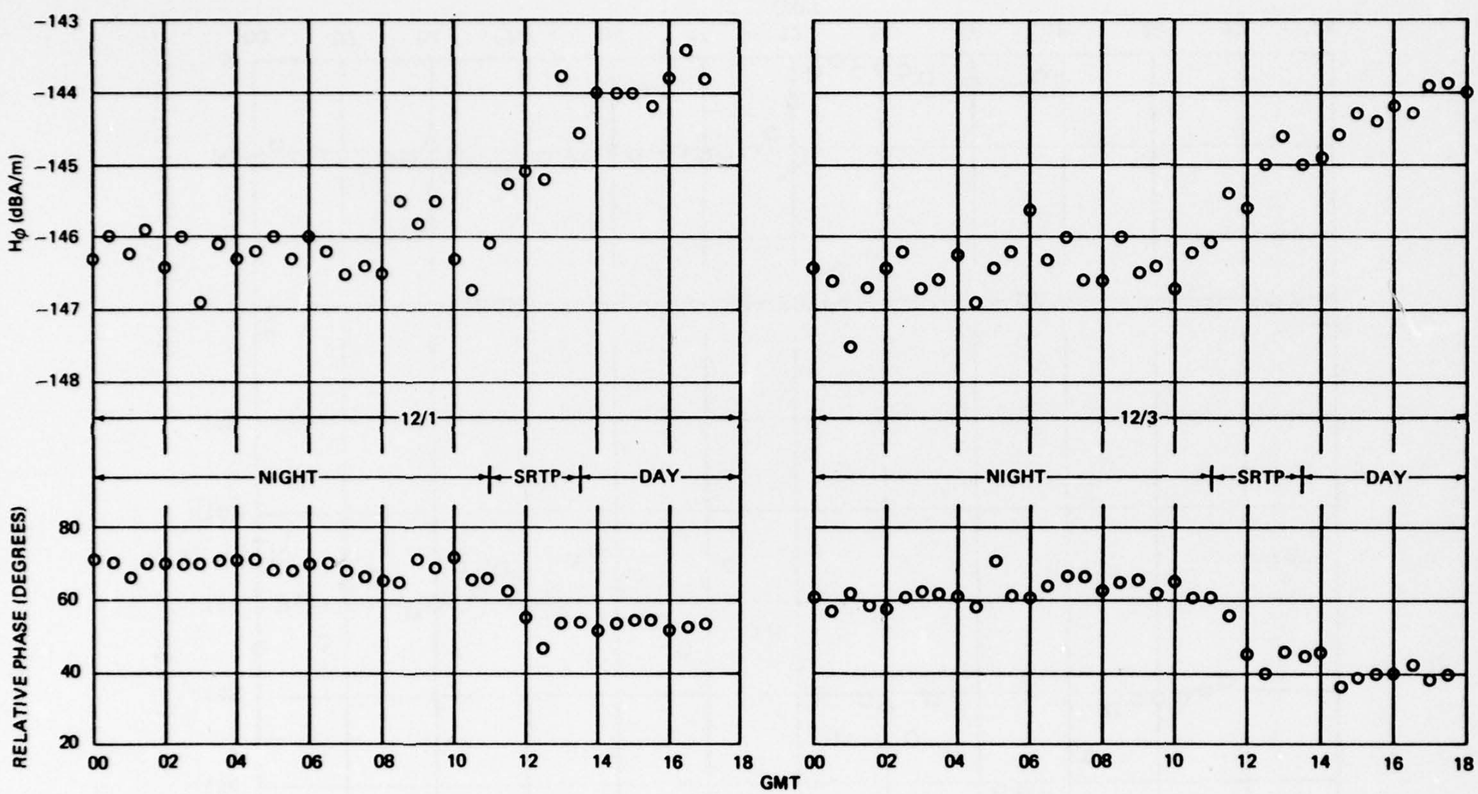

Figure A-63. 1 and 3 December Connecticut Field Strengths Versus GMT (ψ = 21°)

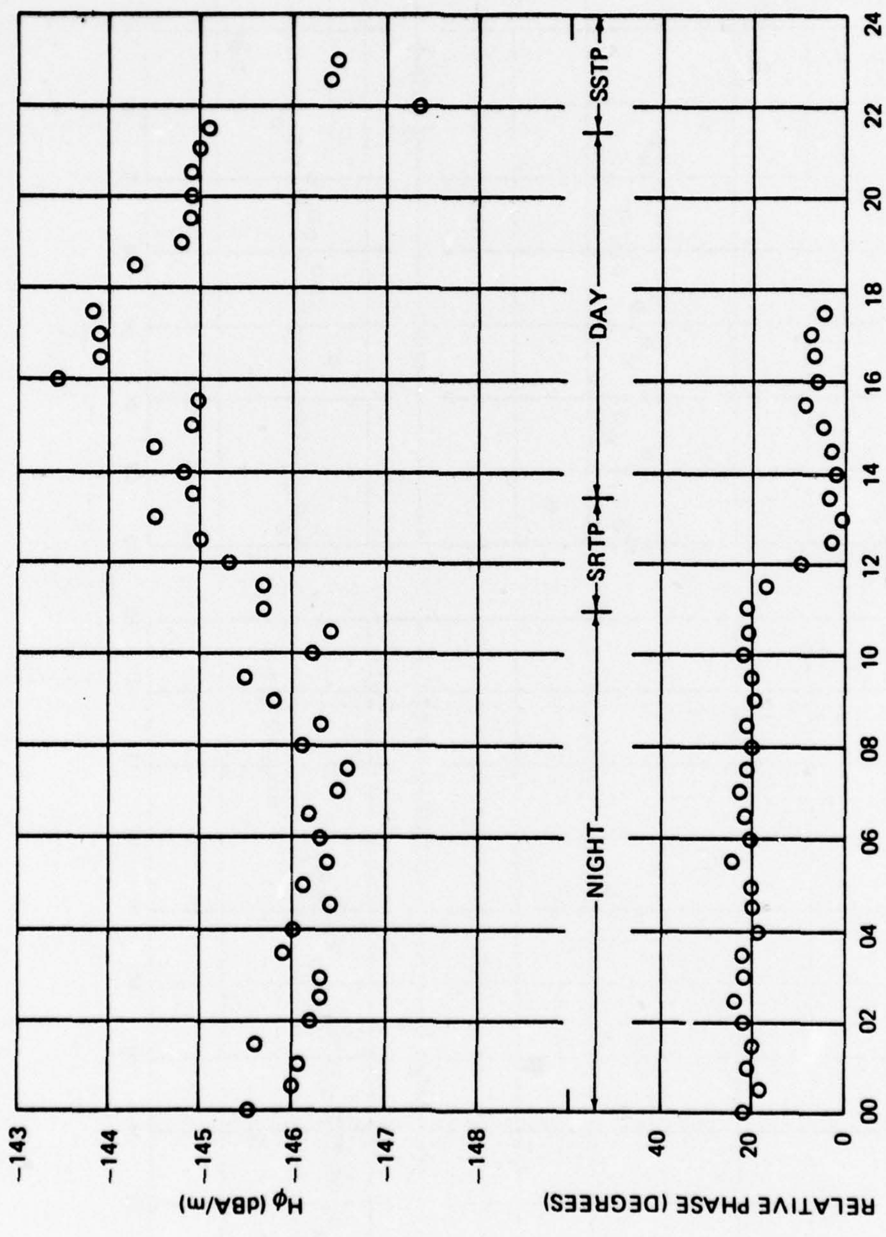

Figure A-64. 2 December Connecticut Field Strengths Versus GMT (ψ = 21°)

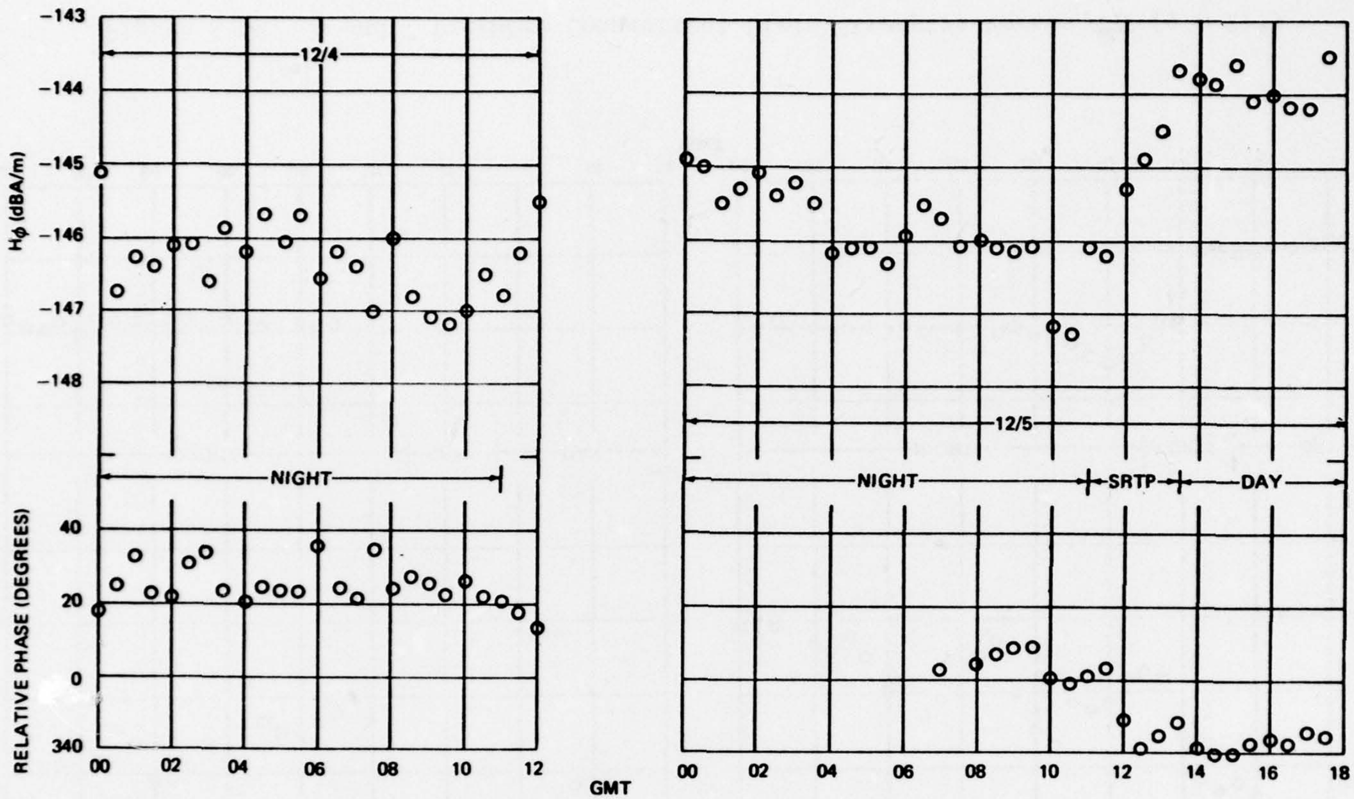

Figure A-65. 4 and 5 December Connecticut Field Strengths Versus GMT (ψ = 21°)

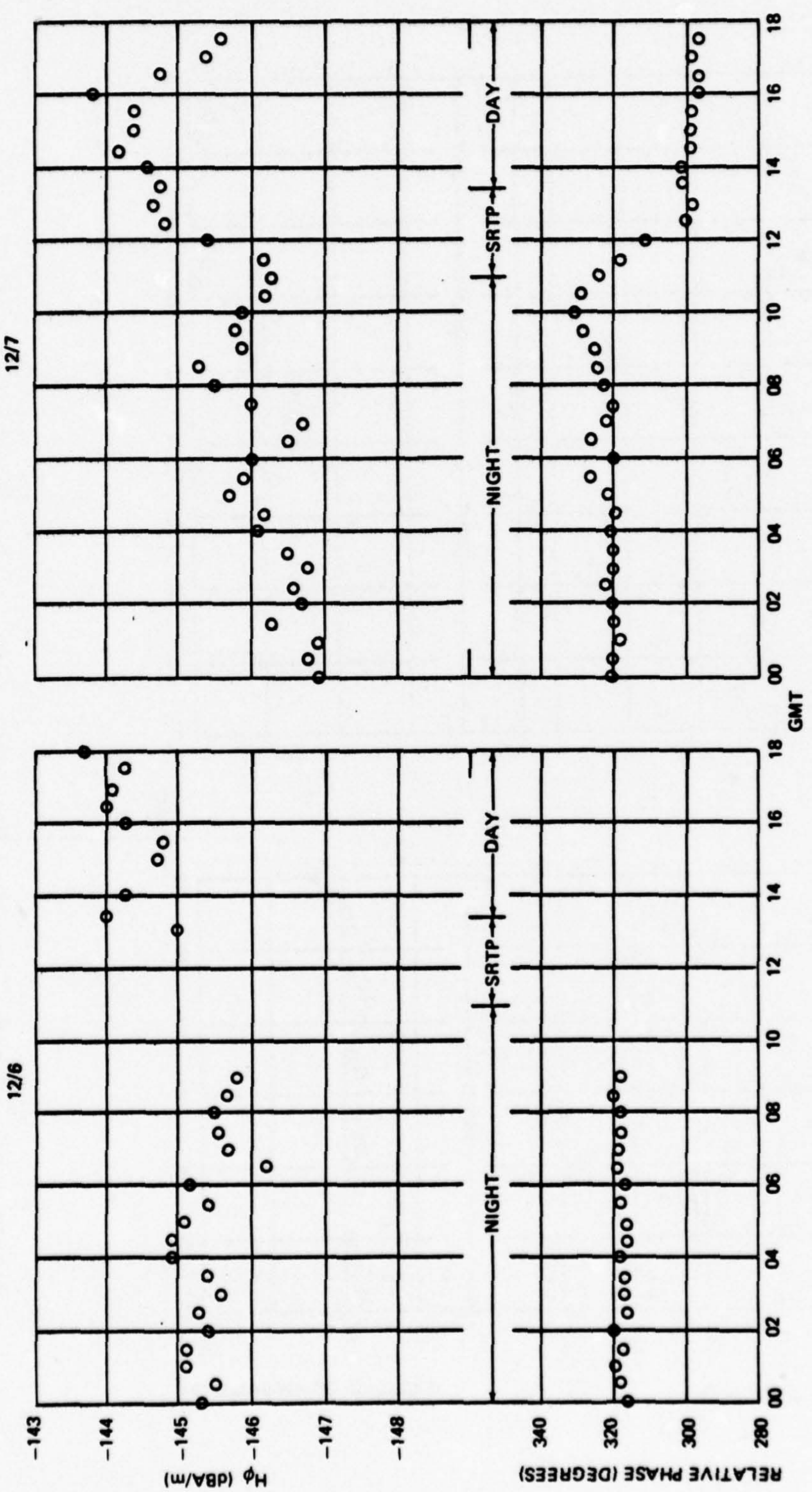

Figure A-66. 6 and 7 December Connecticut Field Strengths Versus GMT (ψ = 21°)

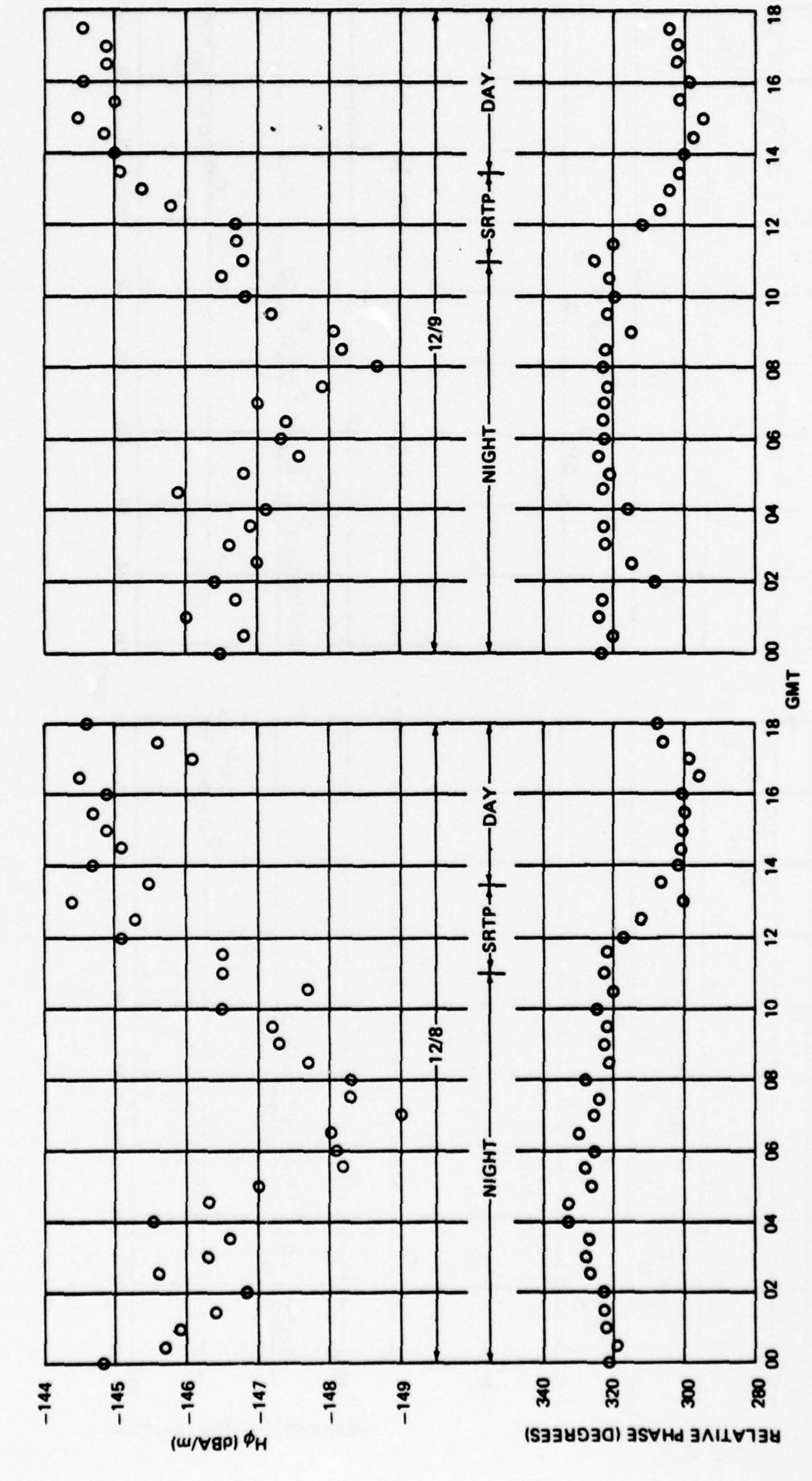

Figure A-67. 8 and 9 December Connecticut Field Strengths Versus GMT (ψ - 21°)

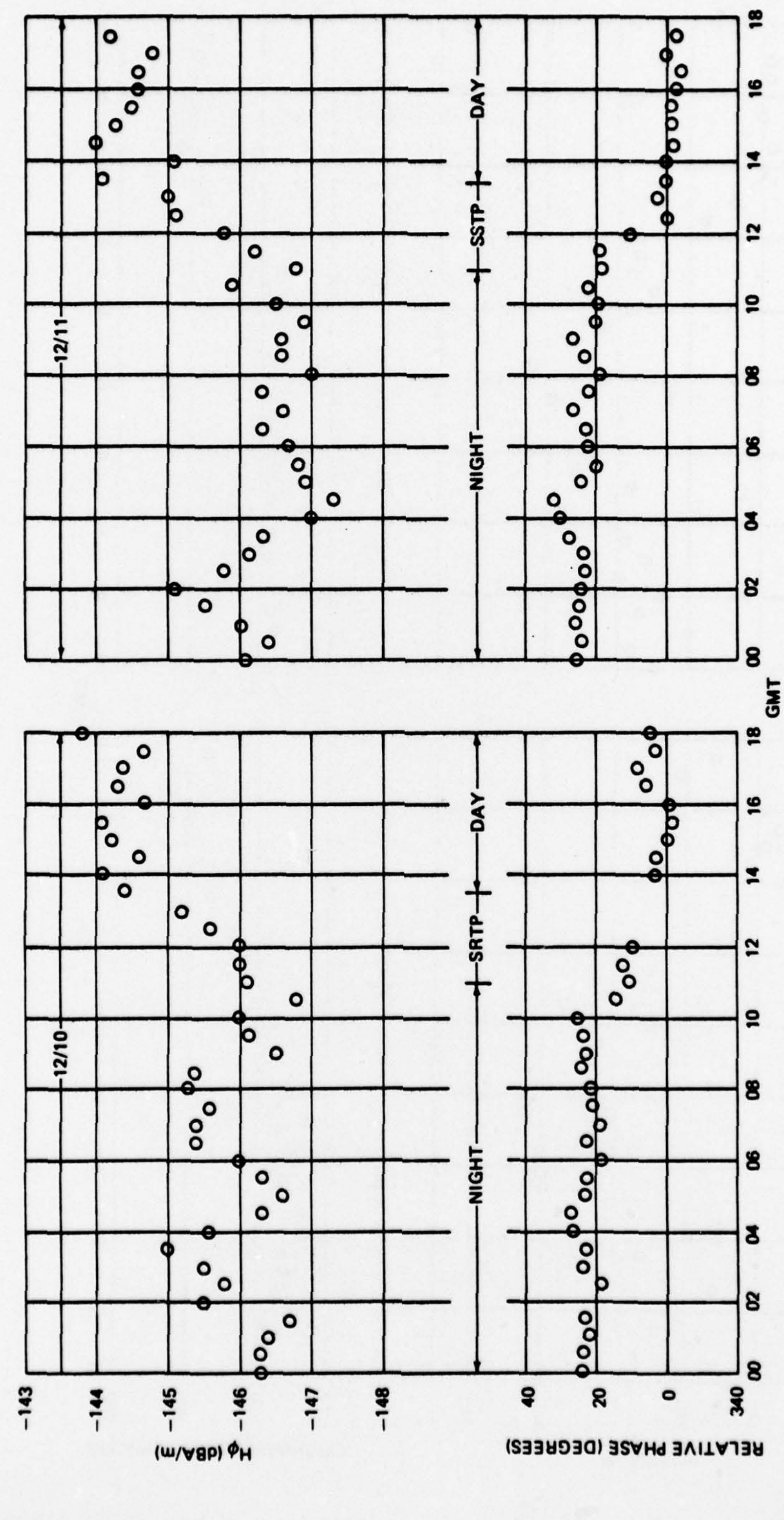

Figure A-68. 10 and 11 December Connecticut Field Strengths Versus GMT (ψ = 21°)

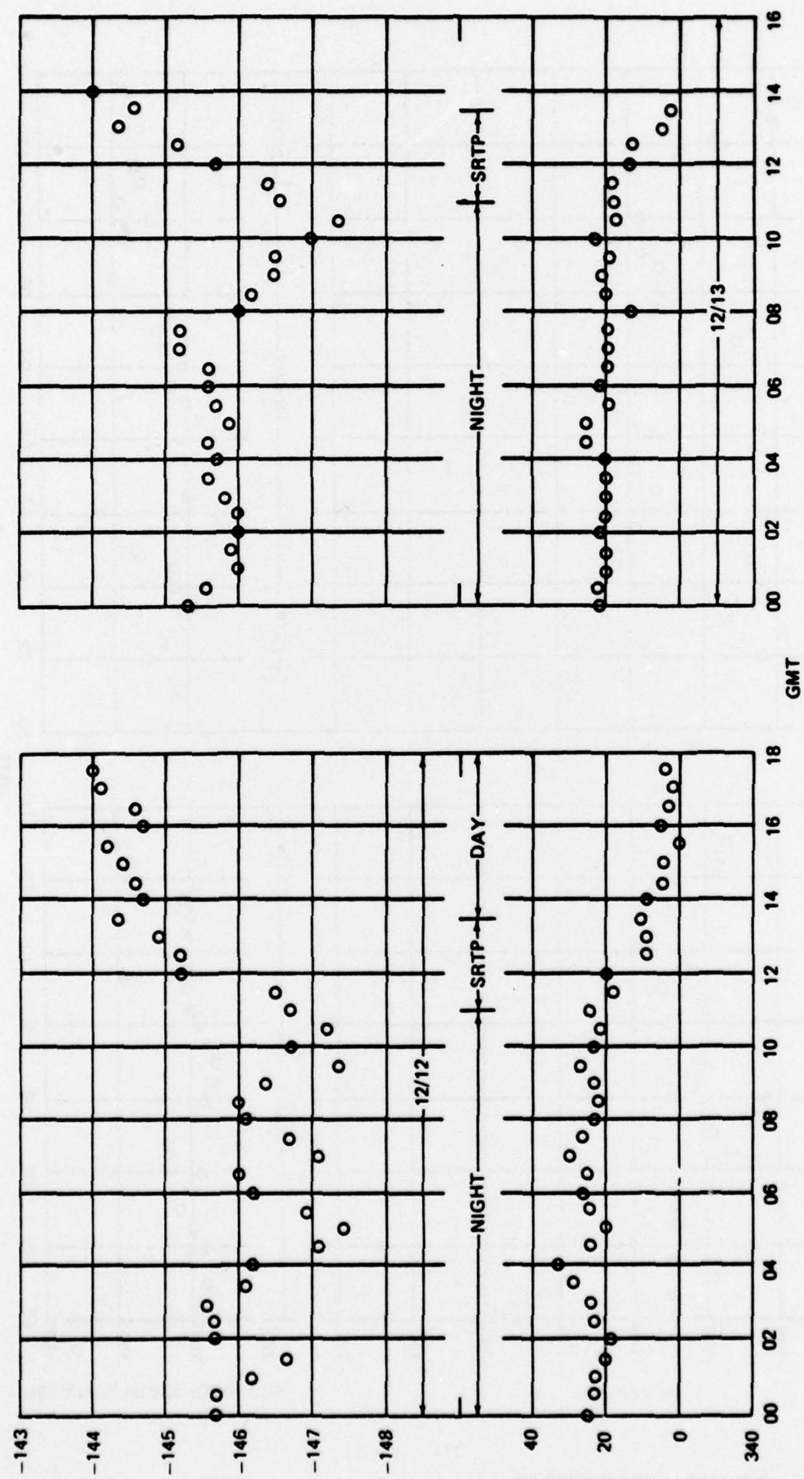

Figure A-69. 12 and 13 December Connecticut Field Strengths Versus GMT (ψ - 21°)

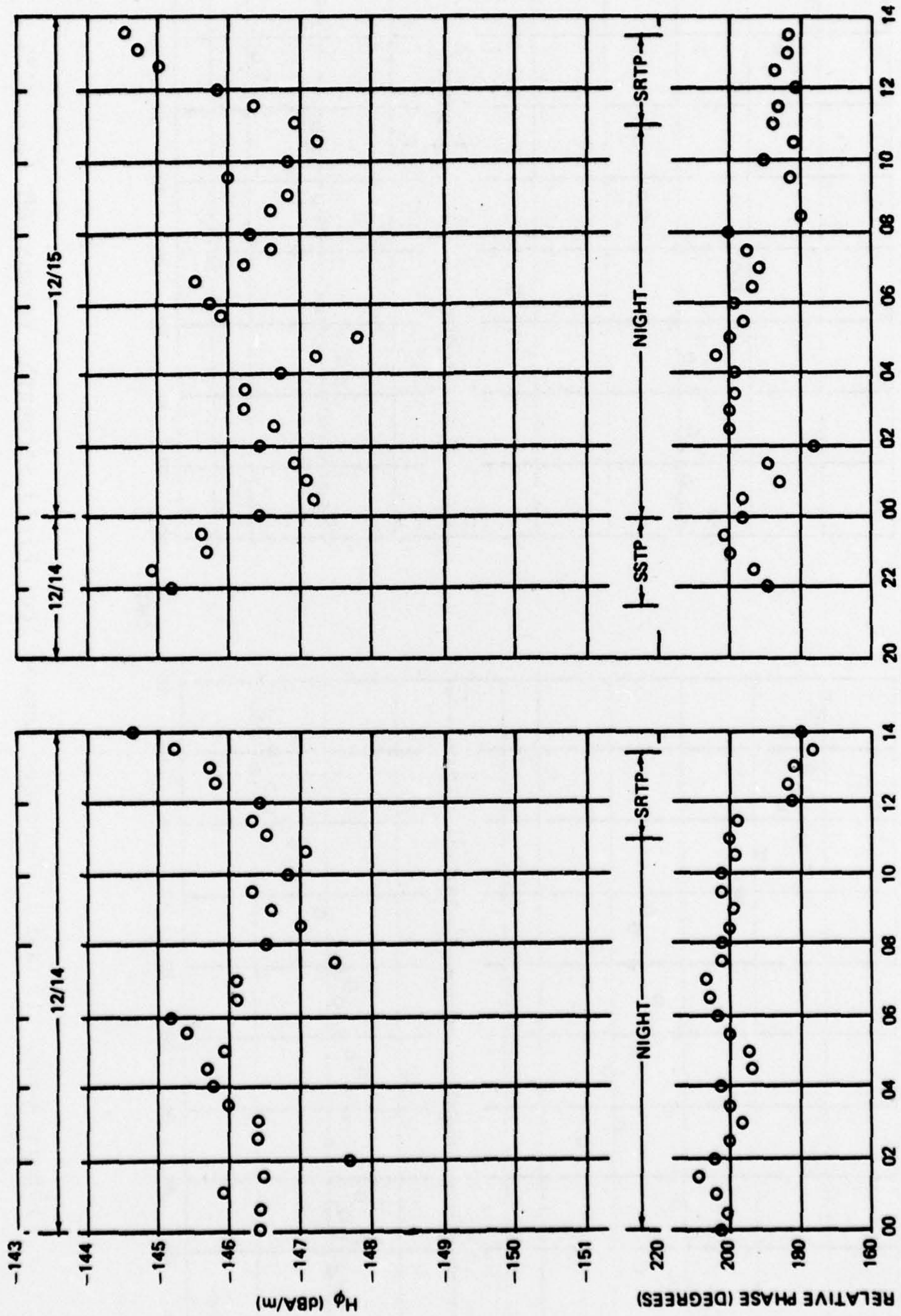

Figure A-70. 13, 14, and 15 December Connecticut Field Strengths Versus GMT (ψ = 21°)

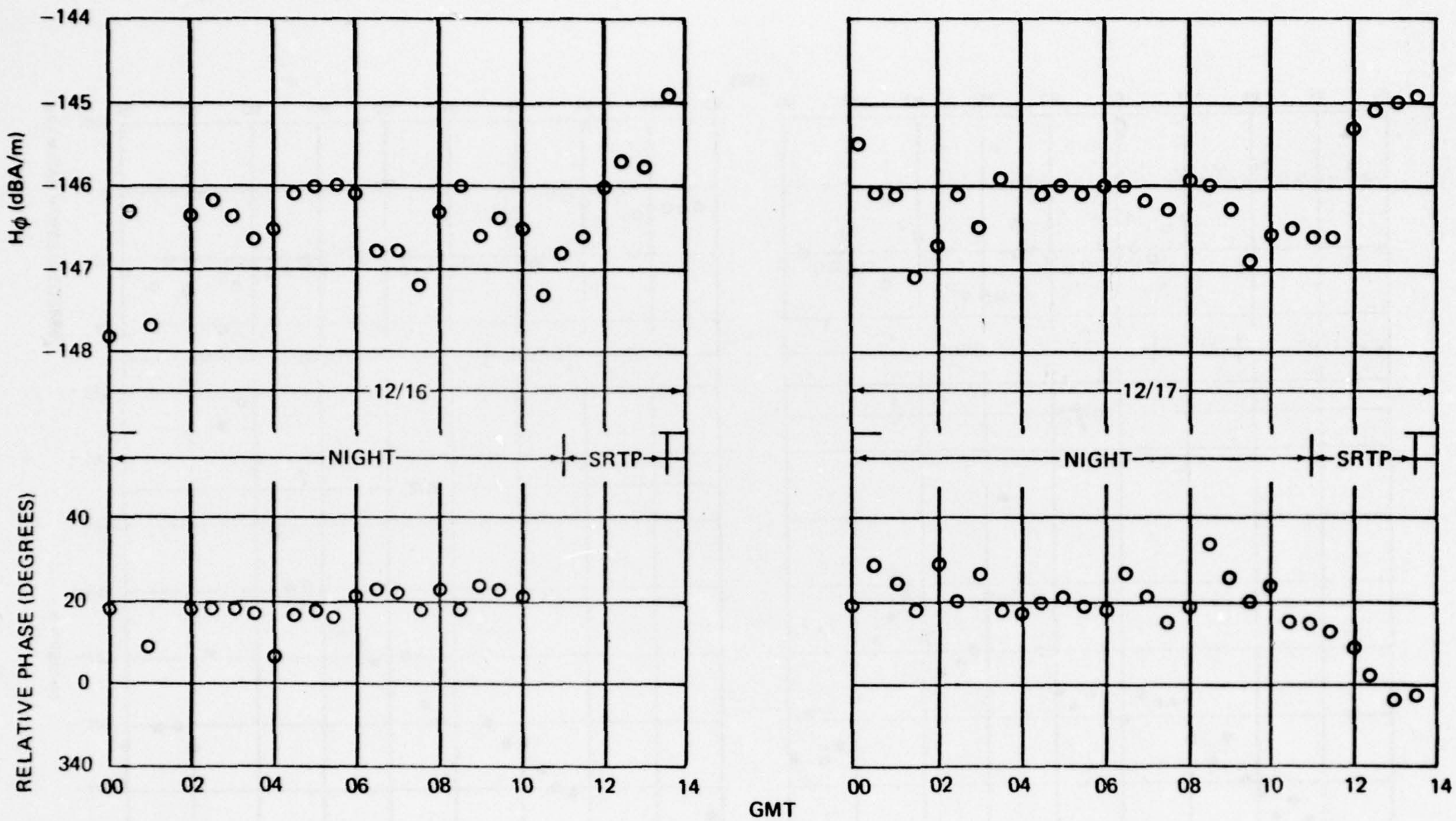

Figure A-71. 16 and 17 December Connecticut Field Strengths Versus GMT (ψ = 21°)

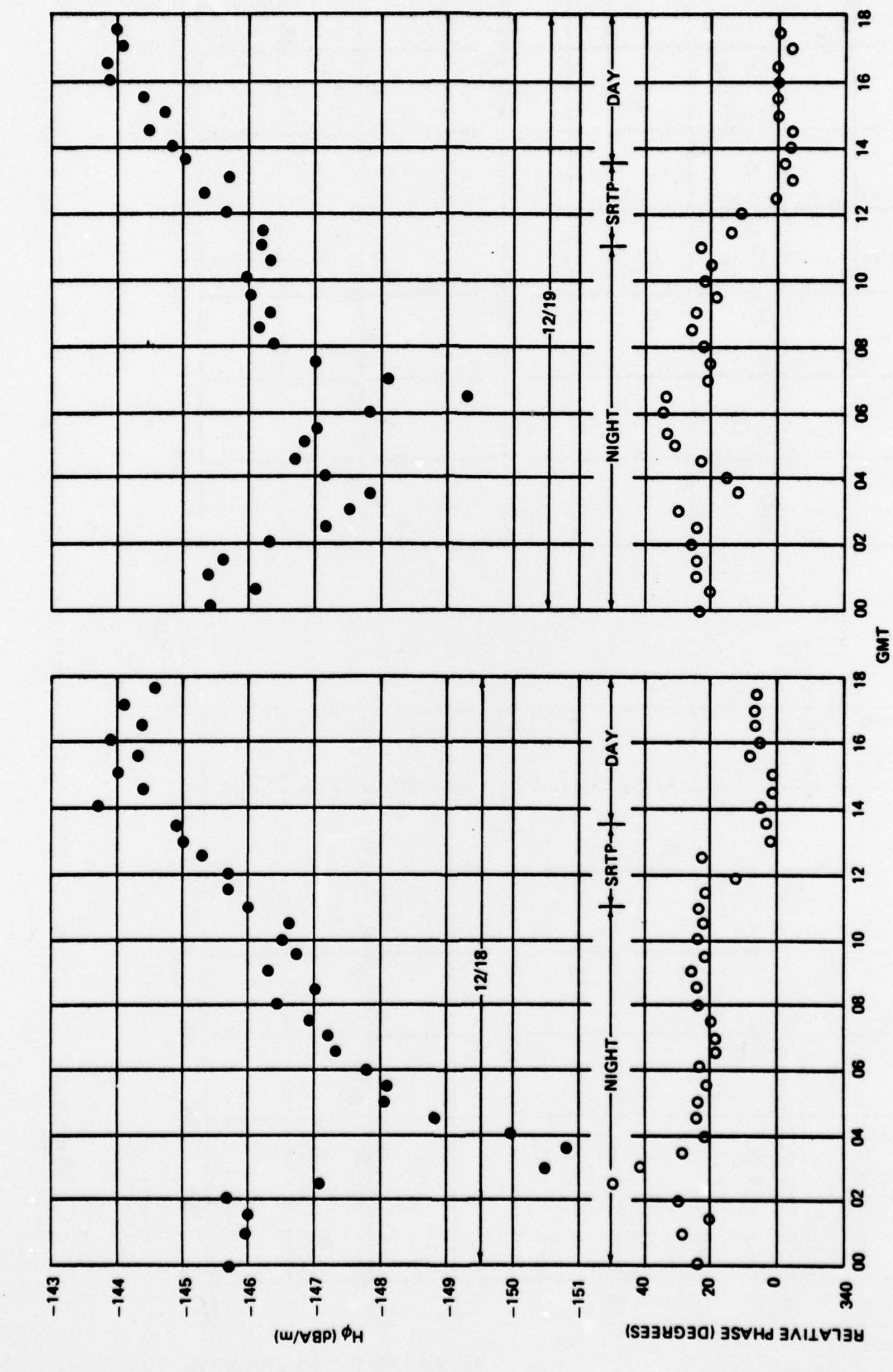

Figure A-72. 18 and 19 December Connecticut Field Strengths Versus GMT (ψ = 21°)

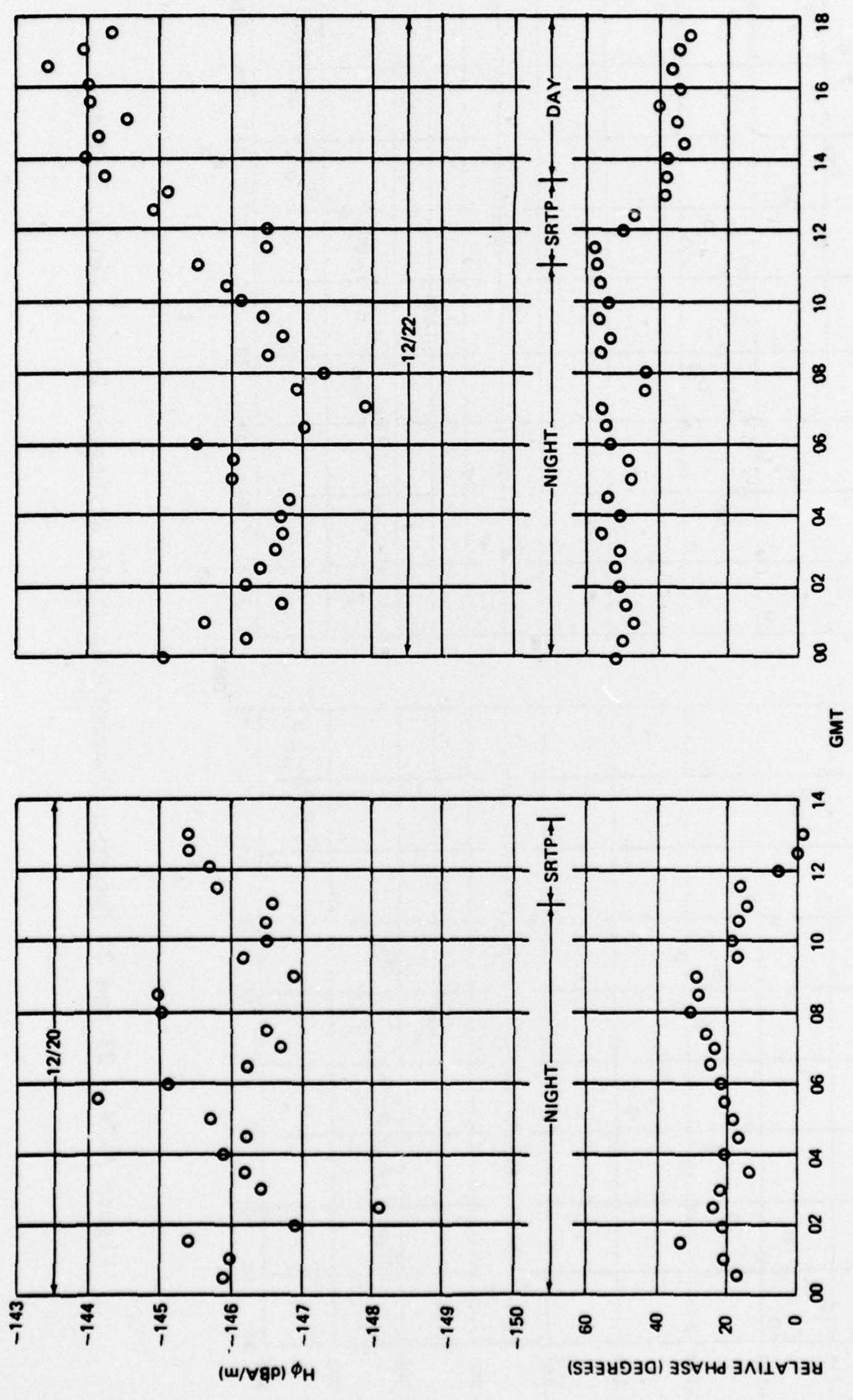

Figure A-73. 20 and 22 December Connecticut Field Strengths Versus GMT (ψ = 21°)

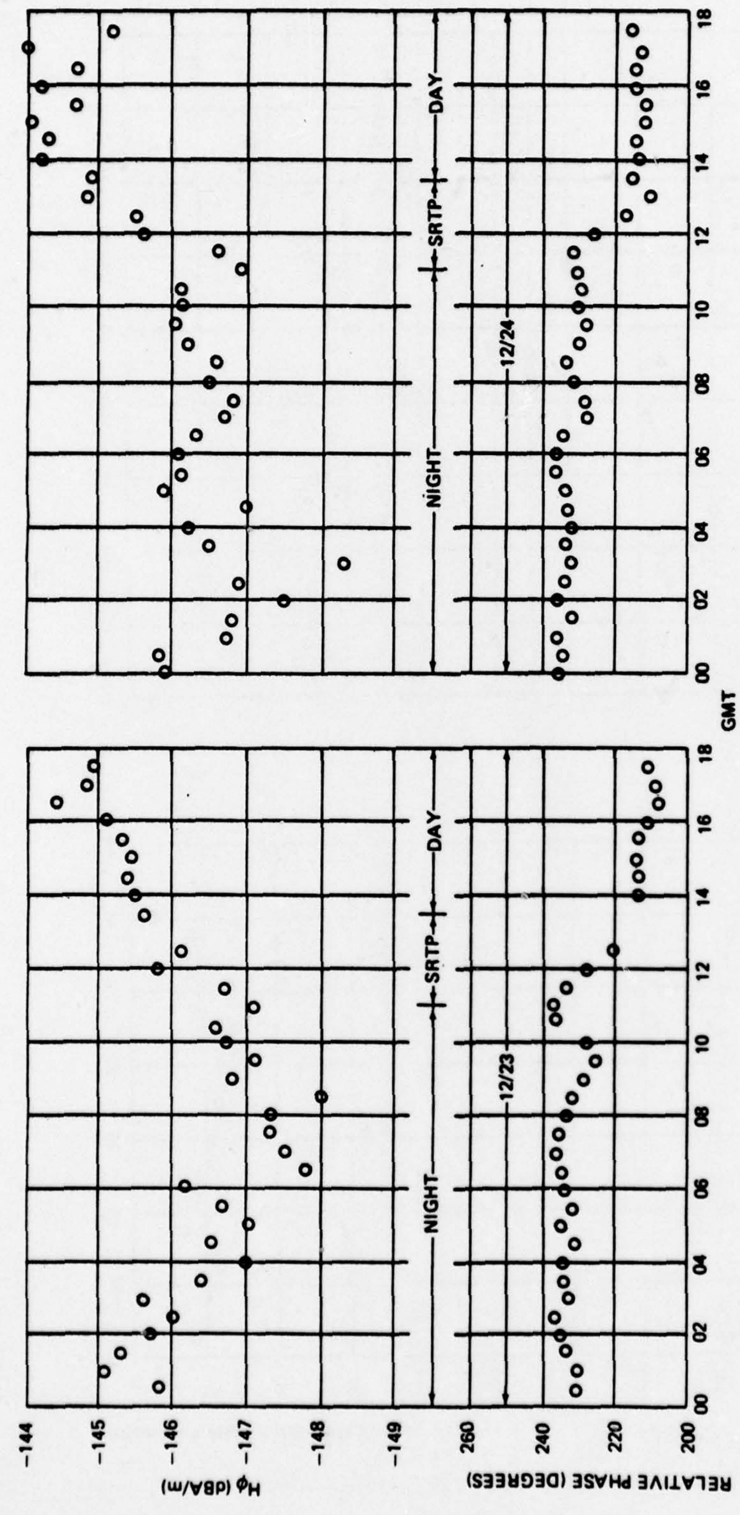

Figure A-74. 23 and 24 December Connecticut Field Strengths Versus GMT (ψ = 21°)

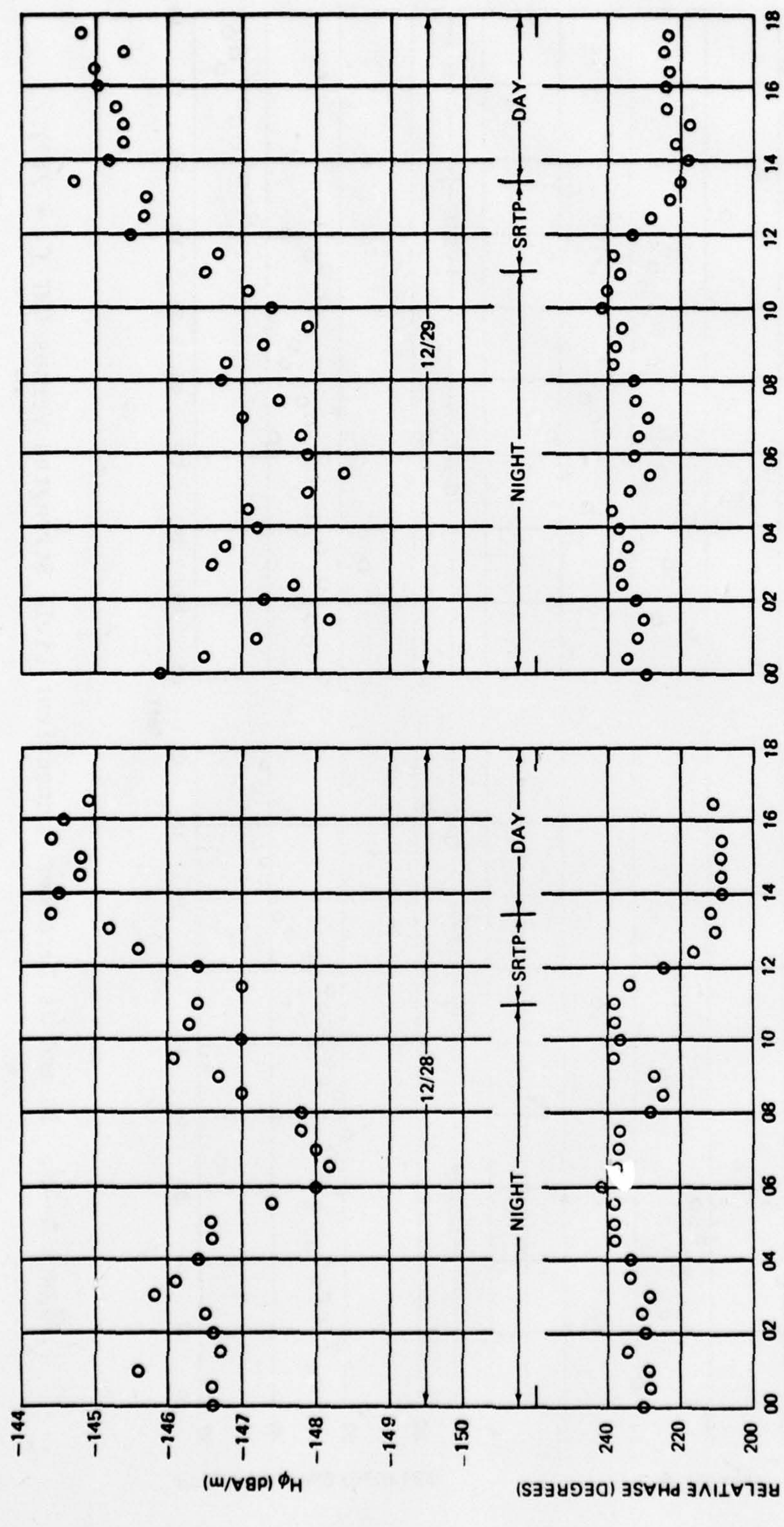

Figure A-75. 28 and 29 December Connecticut Field Strengths Versus GMT (= 21°)

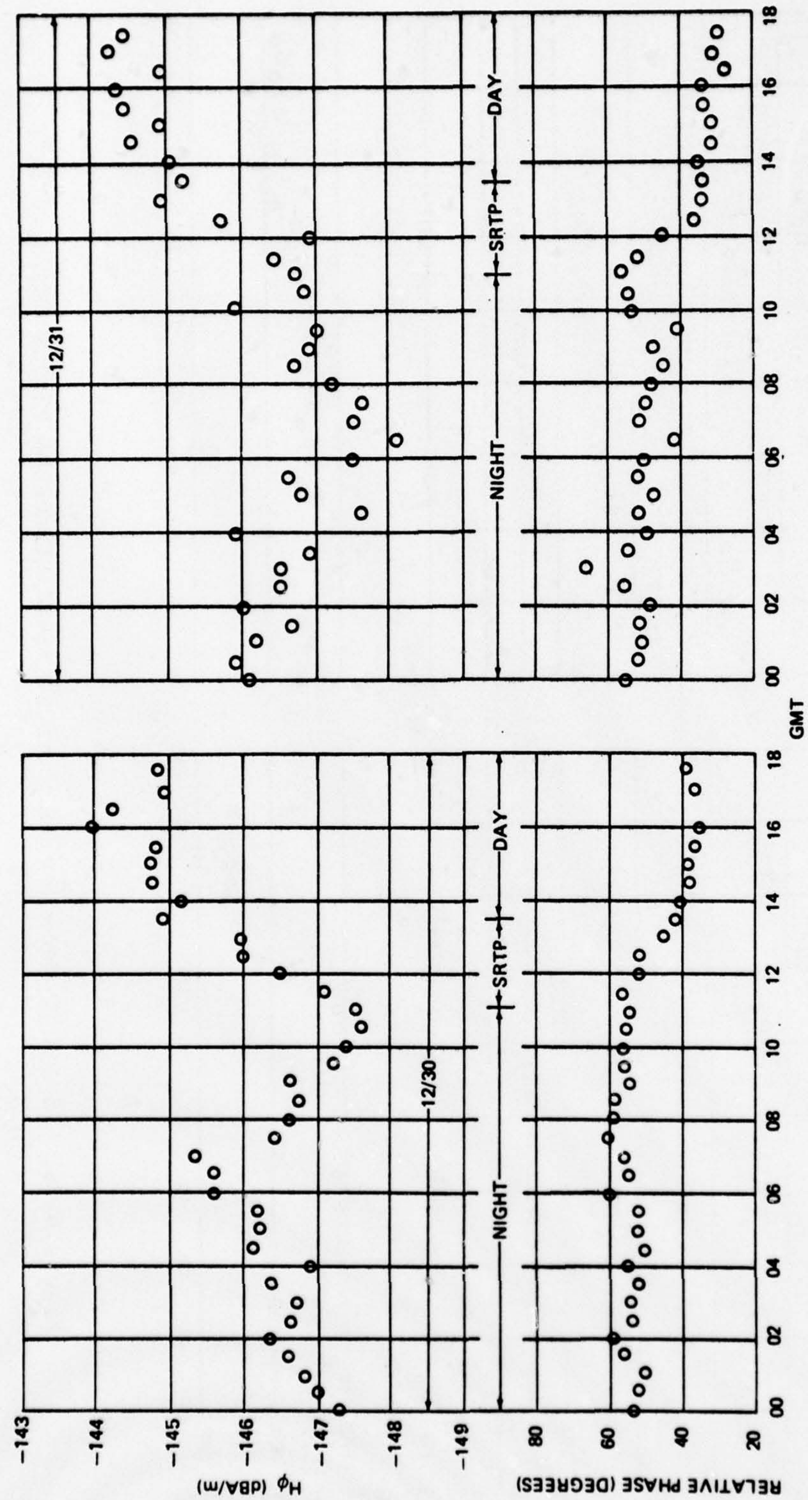

Figure A-76. 30 and 31 December Connecticut Field Strengths Versus GMT (= 21°)

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